312 AMAZING IMAGES & CUTAWAYS INSIDE

THE MAGAZINE THAT FEEDS MINDS

HOW IT WORKS™

ENCE | ENVIRONMENT | HNOLOGY | TRANSPORT | HISTORY | SPACE

INSIDE

SCIENCE OF HAPPINESS
WHY EMOTIONS ARE ALL DOWN TO CHEMISTRY

SKY GIANTS
INSIDE THE UNBELIEVABLE AIRCRAFT THAT DEFY GRAVITY


32,700KG OF THRUST


20-TON LIFT POWER

SHUTTLE LAUNCHERS

NEXT-GEN AIRSHIPS

SECRETS OF LIGHT SPEED
The fastest phenomena in the universe explained

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DEADLY SINKHOLES
What happens when the earth opens up beneath our feet?

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ISSUE 60

WELCOME

The magazine that feeds minds!

Page 28
Out in the wilderness they may look beautiful, but what happens when sinkholes appear in our cities?

According to the laws of physics, as laid down by Einstein's special theory of relativity, light travels at 299,792 kilometres (186,282 miles) per second, and nothing can beat it.

To give that some context, if we were able to travel at light speed, we'd be able to circumnavigate the Earth seven and a half times in a second. But why should this be the cutoff point? Could it ever be exceeded? And how do other cosmic speed demons – from hypervelocity stars to the quickest-ever spacecraft – stack up? We reveal all on page 52.

Also this month we meet the behemoths of the aviation world. Weighing thousands of tons and with wings as long as a football field, these giants look as if they should never get off the ground, but engineers have struck the perfect balance between size and airworthiness. Though, inevitably, now and then our ambition has overstretched our capabilities, as seen in our roundup of aircraft that never took off...

I hope you enjoy my last issue.

Adam Millward
Deputy Editor

Meet the team...

Marcus
Senior Designer
With Marcus on paternity leave, we're sure he's experiencing every emotion under the Sun, so the 'Science of happiness' feature is one for him.

Erlingur
Production Editor
After reading about panic rooms on page 49, I have decided to build my very own, somewhere in the office. You'll never find it...

Jamie
Staff Writer
Steel is crucial to society, going into our cars, buildings and computers. It was fascinating to see this mighty metal being created before my eyes.

Jackie
Research Editor
I enjoyed the light speed feature. Find out why nothing travels faster than photons and learn about other speedy space wonders on page 52.

Helen
Senior Art Editor
It may be a little too cold for me to move there permanently, but the article about life in the taiga was really fun to read.

Jack
Staff Writer
As a big fan of ancient warfare, the Jerusalem siege article really brought out the history geek in me. Ready yourself for battle on page 74.

What's in store

Check out just a small selection of the questions answered in this issue of How It Works...

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CONTENTS

14 SKY GIANTS

From heavyweight helicopters to the longest-ever airship and supersized jumbo jets, we reveal how these aerial goliaths get off the ground…

14




28 Deadly sinkholes


50 Mega-aquariums

Meet the experts…


Laura Mears
Science of happiness
This month Laura gets all emotional as she takes us through the things that determine our mood. You won't know whether to laugh or cry, but by the end you'll see emotions in a whole new light.


Luis Villazon
Sky giants
When you look at the titans of the aviation world, you have to marvel at how they ever take off. This issue Luis reveals what technology powers sky giants of the past, present and future.


Giles Sparrow
Secrets of light speed
The speed of light and other superfast phenomena can be a tricky concept to get your head around but astronomy writer Giles will get you up to speed in no time.


Lee Sibley
Monocycles
Have you ever wondered what would happen were you to cross a unicycle and a motorbike? Well, our regular petrolhead Lee is here to reveal all in his monocycle article.


Vivienne Raper
Life in the taiga
You'd best put on a few layers as Vivienne takes us on a tour of the chilly boreal forest and introduces us to the amazing animals that have adapted to make it their home.

How do we transform venom into its own cure? Find out on page 69

REGULARS

Walking on air

'Floating' walkway allows tourists to experience Canada's incredible natural beauty from a bird's eye view

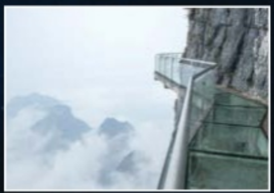
While not one for those who don't have a head for heights, the remarkable Glacier Skywalk joins a growing number of 'midair' platforms in areas of natural beauty around the world. Built using a new cantilever construction technique and super-strong glass, this example is located in Jasper National Park, Canada – some 280 metres (918 feet) above the Sunwapta Valley – and it opens to the public in May 2014. The impressive tech is only surpassed by the view of epic glaciers, raging rivers and the soaring peaks of the Rockies.

'Skywalking' all over the world

Check out three more see-through walkways

Grand Canyon, USA

Built in 2007, the Skywalk is a horseshoe shape and provides breathtaking views of the world-famous American canyon.



Tianmen Mountain, China

A dizzying 1,433m (4,700ft) high, shoes are forbidden on the walk so the World Heritage Site must be traversed barefoot or in your socks!

Aurland, Norway

Looking much like a long straight catwalk extending into the air, the 30m (98ft)-long observation deck looks out over the stunning Scandinavian fjords.

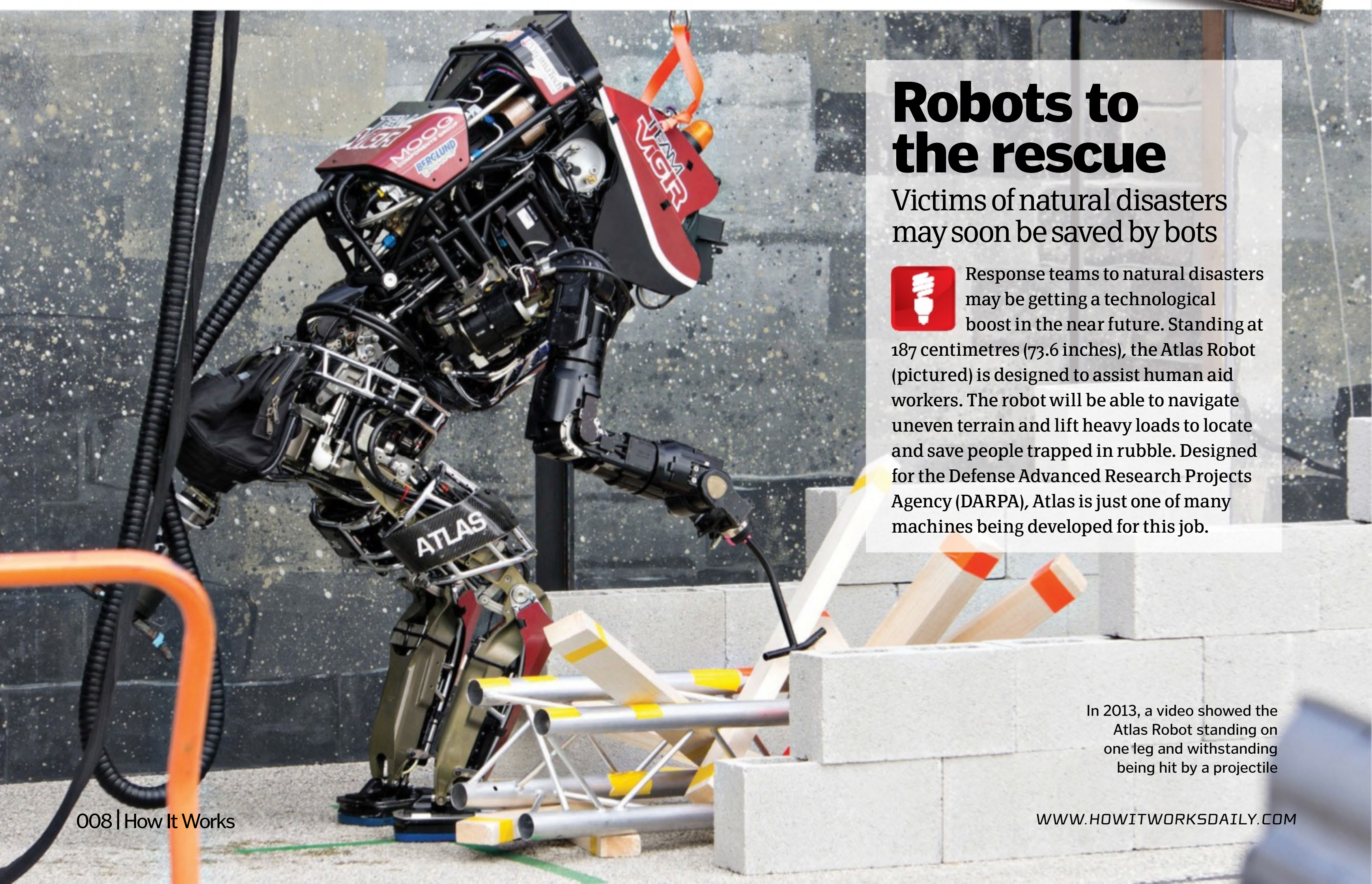
Only about 5,000 black rhinos are left in Africa, so immediate action is needed to save the species

SAVE RHINOS NOW

Fight to save the black rhino

World of Animals joins mission to protect this majestic creature

The largest black rhino sanctuary in East Africa, Ol Pejeta, is a not-for-profit organisation and is home to 100 black rhinos. Forever under threat from poachers, the black rhino is now one of the most endangered species on Earth. The total population has plummeted from around 65,000 to around 5,000. One subspecies in particular – the Diceros bicornis michaeli, or eastern black rhinoceros – only has an estimated 600-800 left. **How It Works'** sister magazine **World of Animals** is proud to support Ol Pejeta and the fight to save the black rhino from extinction by donating ten per cent of its profits to the sanctuary.



Robots to the rescue

Victims of natural disasters may soon be saved by bots

Response teams to natural disasters may be getting a technological boost in the near future. Standing at 187 centimetres (73.6 inches), the Atlas Robot (pictured) is designed to assist human aid workers. The robot will be able to navigate uneven terrain and lift heavy loads to locate and save people trapped in rubble. Designed for the Defense Advanced Research Projects Agency (DARPA), Atlas is just one of many machines being developed for this job.

In 2013, a video showed the Atlas Robot standing on one leg and withstanding being hit by a projectile

Antarctica from space

First images from the Copernicus Observation Programme reveal Earth in a whole new light

This incredible image was taken by the European Space Agency's Sentinel-1A satellite and is one in the first batch of shots to be captured for the Copernicus Programme. In the largest-ever civil observation of Earth to monitor environmental changes, the first Sentinel launched on 3 April. This picture reveals the varying thickness of sea ice on the northern Antarctic Peninsula. It should help us to navigate these treacherous waters as well as providing an insight into the effects of climate change.

Sentinel-1A in numbers

17
Number of Sentinel launches planned for next decade

693 km
Altitude of satellite in its Sun-synchronous orbit

£230 million
Estimated construction cost of the Sentinel-1A satellite

1.4 Tbit
The end of life capacity of science data storage on board

Engaging with evolution

Anatomist and TV presenter Professor Alice Roberts reveals why she's fascinated by the human race – both past and present

You're going to be talking about your new book *The Incredible Unlikeliness Of Being* at the British Science Festival in September – tell us what it's about.
My book is about the development of a human being, starting with the moment when egg and sperm meet. I've always been fascinated by embryology – this transformation of a single cell, the fertilised egg, into a complex body with hundreds of different types of tissue and functioning organs. But the book is also about evolution, because there are moments in the development of a human embryo when you glimpse echoes of ancient ancestors – earlier stages of evolution. The human embryo has a yolk sac, which shows we're related to animals that lay eggs. At five weeks after fertilisation, the human embryo has ridges along its neck that look like the precursors of gills, recalling our fishy ancestors.

So how do we differ from our ancestors?
The book is about our ancestors but also about our evolutionary relationships with other living animals. Unsurprisingly, we have more in common with close relations like chimpanzees and gorillas, but there are also important, deep-rooted similarities between us and our distant cousins. You might not think you have much in common with a fruit fly, but both of you have a segmented body and the genes that control the pattern of your body segments are essentially the same genes that do the job in a fruit fly.

Is there any way to predict how humans will evolve in the future?
The structure and function of our bodies is a product of our embryological development. As animals evolve, the possibilities aren't endless – they are constrained by what went before. While it's impossible to predict how humans will evolve in the future, we can certainly suggest that some changes are extremely *unlikely* to happen. So I'll stick my neck out and say that humans are extremely unlikely to ever evolve an extra pair of arms or eyes in the back of their heads!

Would you say there is more equality in science than other fields?
Only 17 per cent of science professors in the UK are women. A study published last year looking at grants for research into infectious disease showed that studies led by women received 43 per cent less money on average than those where men led the research group.

The House of Commons Science Technology and Committee report on 'Women in Scientific Careers' – published in February – made recommendations I believe should be taken very seriously if we're ever going to get near to equality in science careers. Those recommendations included a big overhaul of the structure of careers – something we're going to have to engage with if we're really going to make a difference.

Who are your biggest female scientific inspirations?
There are many! But to name just a few: Mary Anning, Mary Leakey, Dorothy Hodgkin and Rosalind Franklin.

Do you feel the British public is engaging with science as much as they should?
I tend to approach this from the other way round: are scientists engaging with the public as much as they should? I think there's an emerging acceptance that public engagement should be an integral part of a scientist's job, rather than an add-on. But there's still a lot more we could be doing, in particular, to reach out to people and communities who don't naturally gravitate towards science. I think that one way of doing that is to stop treating science as though it were somehow separate from the rest of our culture – it's part of it.

Most people will know you best from TV shows like *Coast* and *Time Team*. Have you got any more programmes on the horizon?
After a break from filming science documentaries to have my second child, I'm involved with several projects this year. 2014 marks the 300th anniversary of the original Longitude Prize, won by the watchmaker John Harrison. In May, BBC2's *Horizon* will help to launch the new Longitude Prize, where the public will be invited to vote for one of six important scientific challenges, with a £10 million [$16.8 million] reward for anyone who can solve the chosen challenge. I'm also working on a *Horizon* programme about the differences between male and female brains, with fellow BBC science presenter Michael Mosley.

Why is the British Science Festival being held at the University of Birmingham this year?
2014 is officially Birmingham Year of Science, and the British Science Festival really is the jewel in the crown of this year-long celebration of science in the city. Birmingham has an incredibly rich scientific heritage; it was a centre of activity in the Industrial Revolution, the birthplace of many inventions, from celluloid film to medical gauze, as well as being home to the Lunar Society.

There are almost 14,000 students studying life sciences across Birmingham's five universities, the University of Birmingham has the second-largest medical school in the country and the city employs more than 75,000 people in the life sciences sector.

Alice will be talking at the British Science Festival, taking place 6-11 Sept. For more info go to www.britishsciencefestival.org or Twitter @BritishSciFest.

"Public engagement should be an integral part of a scientist's job, rather than an add-on"

Professor Alice Roberts at the University of Birmingham with an old friend...

10 COOL THINGS WE LEARNED THIS MONTH

Asteroid impacts can preserve prehistoric life

You might assume that when a space rock smashes into our planet at several thousand miles per hour there can only be one result: destruction. But geologists studying impact sites in the Pampas of Argentina have found that meteorites also have the capability to freeze plants – and potentially other microbial life – in time. It all comes down to heat. When the asteroid makes contact with Earth, temperatures of over 1,500 degrees Celsius (2,700 degrees Fahrenheit) can be generated, instantly melting the surface. As the hot liquid rock is thrown up into the air, it can land on nearby vegetation and solidify into glass, preserving plant matter and other chemicals within. It's thought this technique could also be used to search for former life on Mars.

The remarkably preserved plant material is estimated to be 9 million years old

New lasers could make lightning

It's long been known that rain and lightning are the result of natural interactions between charged particles in the clouds. Many have argued that lasers have the potential to excite these ions and electrons and artificially trigger a storm, perhaps providing an invaluable weapon against drought. The main problem has been producing a powerful enough laser beam. But now two photonics and optics graduates think they have the answer: two laser beams. The first high-intensity laser is surrounded by a less-intense, doughnut-shaped beam, which supplies the additional energy to prevent the first one breaking down. Still in the preliminary stages, so far the doubled-up laser, or dressed filament, has reached 2.1 metres (seven feet), but the researchers think 50 metres (164 feet) or more can be achieved.

Flies move like fighter jets

New research has shed light on why flies are such expert aviators. Using high-speed cameras, scientists at the University of Washington recorded the tiny wing and body movements enabling them to bank and pitch away from threats, much the same as a state-of-the-art fighter jet, and they can alter direction in less than five milliseconds. The next stage of the research is to put fruit flies in a special flight simulator to record neural activity, which might help explain their lightning-quick responses.

Oceans are the safest place for nuclear power

Since 2011's Fukushima disaster, there has been a concerted effort to rethink the future of nuclear power to make it safer. One of the most radical suggestions to date has been proposed by a group of science and engineering professors, along with nuclear power and offshore construction specialists: to build power plants at sea. Taking inspiration from oil and gas drilling rigs, they argue that floating facilities far from land are the safest place for nuclear reactors. Not only are they surrounded by a ready source of cold water to instantly cool down a meltdown situation, but they'd also be unaffected by tsunamis and earthquakes.

Wind turbines take off

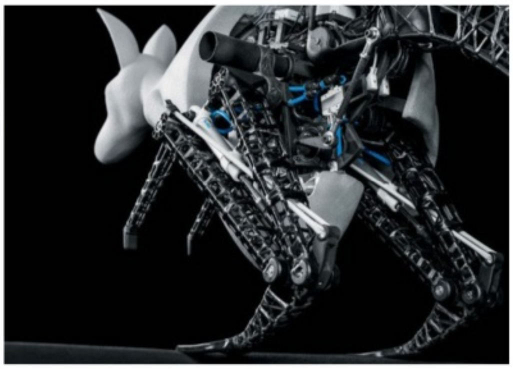
Green credentials aside, some people argue wind turbines are a blot on the natural landscape that also disrupt local wildlife. MIT-founded Altaeros Energies might have the solution in the Buoyant Airborne Turbine (BAT). Comprising four main components – a helium-inflated shell, turbine, tethers and a ground station – this floating wind-catcher is based on tried-and-tested aerostat technology and boasts several advantages over its ground-based cousins. For one thing, winds are generally stronger and more consistent at higher altitudes and the BAT can autonomously adjust its altitude to follow the breeze. Not only that, but the ground station is built onto a trailer so the entire assembly can be easily relocated.

Hubble is getting better with age

Launched over 24 years ago, the Hubble Space Telescope is now using a new technique called spatial scanning to measure up to ten times farther than before. The technique works with the same parallax trigonometry the scope uses to calculate cosmic distances, where Earth's orbit and the star under scrutiny serve as points in an imaginary triangle. Spatial scanning improves the accuracy when working with smaller angles, enabling it to study stars as far as 10,000 light years away.

Superfast bikes look a bit like jellybeans

Currently being developed at the University of Liverpool, this odd-looking contraption is, in fact, a bike and could go down in history as the fastest human-powered vehicle. Called the ARION1, its makers claim the velocipede is 40 times more aerodynamic than a Bugatti Veyron and could travel at 145 kilometres (90 miles) per hour on a smooth road. The current record for a pedal-powered vehicle is 133.8 kilometres (83.13 miles) per hour – set in 2013 – but the ARION1 is seeking to better this at 2015's World Human Power Speed Challenge.



Robot kangaroos can hop for ever

Proving yet again that engineering can learn much from the natural world, industrial technology company Festo has built BionicKangaroo. Standing about a metre (3.3 feet) high and weighing only seven kilograms (15 pounds) – so technically more like a wallaby than a kangaroo – the man-made marsupial can nevertheless leap an impressive 0.8 metres (2.6 feet). But most amazing of all is how it uses elastic springs, along with pneumatic valves and cylinders, to convert kinetic energy from one jump into potential energy for the next, so in theory the robotic 'roo can just keep on hopping.

Artists and non-artists think differently

In the wake of research that flagged up differing neural circuitry in the brains of men and women last year, a new study suggests that artists also have a unique brain structure. A scanning technique called voxel-based morphometry was used to map grey and white matter in the brains of art students and non-artists. The former group had more neural matter in the precuneus region, known for its visual-spatial abilities, as well as in the cerebellum and motor cortex, which deal with fine movements. What remains to be determined is whether artists are born with this brain structure or if it adapts in response to upbringing and creative pursuits.

Earth 2.0 has been found

In an astronomical breakthrough, an exoplanet virtually the same size as Earth has been spotted in the habitable zone of its star. Kepler 186f is located some 500 light years away in the Cygnus constellation. Its sun is about half the size of our own, and it completes its orbit in 130 days. It has four neighbouring planets that are closer to the star, but Kepler 186f is the only one located in the 'Goldilocks zone', with conditions allowing for liquid water – and therefore life – on the surface.

SKY GIANTS

Discover how the world's biggest aircraft combine clever engineering and advanced materials to defy gravity

The first powered flight in 1903, by Orville Wright, covered a distance of just 37 metres (121 feet). He could have taken off and landed – twice – across the wings of an Airbus A380. In the 110 years since that flight, engines have moved from pistons to turbo jets; construction materials have switched from wood and cloth to aluminium alloys and carbon fibre; and wing design has dropped the draughtsman's table in favour of computational fluid dynamics.

For passenger aircraft, increasing size offers greater economies of scale; large planes can fly farther without stopping and they use less fuel per passenger-mile. That's true for cargo planes as well but truly huge cargo planes can carve themselves a niche even when the cost per ton is higher. That's because some loads are just so massive they can *only* be carried by the largest planes. The heaviest, the widest, the longest or simply the largest, the aircraft included here can all claim to be the biggest in the world, according to some criterion. What they all have in common, though, is jaw-dropping specs. Whether you need to airlift a downed Chinook helicopter from a warzone or send off a 220-ton shuttle into space, there's always going to be a demand for mega-planes like these…

KEY DATES
AVIATION MILESTONES

1907
The Breguet-Richet gyroplane makes the first manned helicopter 'flight', although it is tethered to the ground.

1933
The first true airliner, a Boeing 247, carries ten passengers from New York to LA in 20 hours.

1939
Heinkel He 178, the first turbojet aircraft, flies. It reaches speeds of over 644km/h (400mph).

1964
The test vehicle for the Apollo Lunar Lander is the first electronic fly-by-wire aircraft with no hydraulic backup.

1986
Dick Rutan and Jeana Yeager fly around the world without refuelling in the Rutan Voyager.

DID YOU KNOW? *Boeing's 747 fleet has flown more than 5.6bn passengers – equal to 80 per cent of the world's population*

Catamaran fuselage
Fuel tanks are balanced on either side so that the massive payload can be slung from the middle.

Payload
The payload is released some 9,000m (29,528ft) up and is boosted to orbit by a three or four-stage rocket.

Engines
The six jet engines are cannibalised from a pair of used 747-400 planes. The total thrust is 252kN (56,750lbf).

Integration system
Developed by Dynetics Inc, which has extensive experience with air launch systems used on military missile systems.

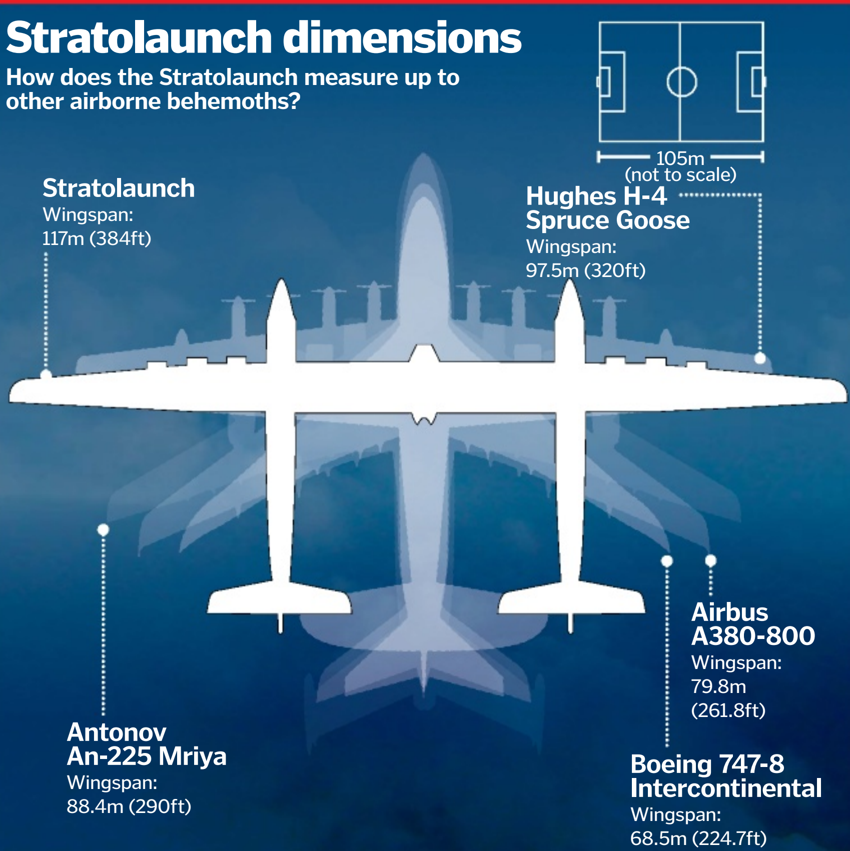
Cockpit
The fully fly-by-wire system balances the control inputs to compensate for the off-centre pilot's position.

Wings longer than a soccer pitch
Stratolaunch

Funded by Paul Allen, co-founder of Microsoft, the Stratolaunch is still at the design stage. But if it is ever built, it will have the largest wingspan of any aircraft ever made. Taking off from a runway almost 3.7 kilometres (2.3 miles) long, it will climb to 9,000 metres (29,530 feet) before releasing a 220-ton rocket that will fly the rest of the way into orbit. Launching rockets this way avoids the thickest part of the atmosphere and grants a greater choice of possible orbital trajectories. It effectively turns the Stratolaunch into a reusable first-stage booster.

The technical challenges, however, are formidable. Air-launching rockets isn't new; the early test flights of the Space Shuttle involved the Enterprise being launched from the back of a 747. But the Shuttle was a glider, empty of fuel and only weighed 68 tons. The Pegasus II rocket carried by Stratolaunch weighs more than three times this and is full of explosive rocket fuel. Stratolaunch also needs to pull into a steep climb just before releasing the rocket, without plunging itself into a fatal stall. Designing an airframe to cope with these strains will push aviation technology to the limits.

Stratolaunch dimensions
How does the Stratolaunch measure up to other airborne behemoths?



The statistics…

Stratolaunch

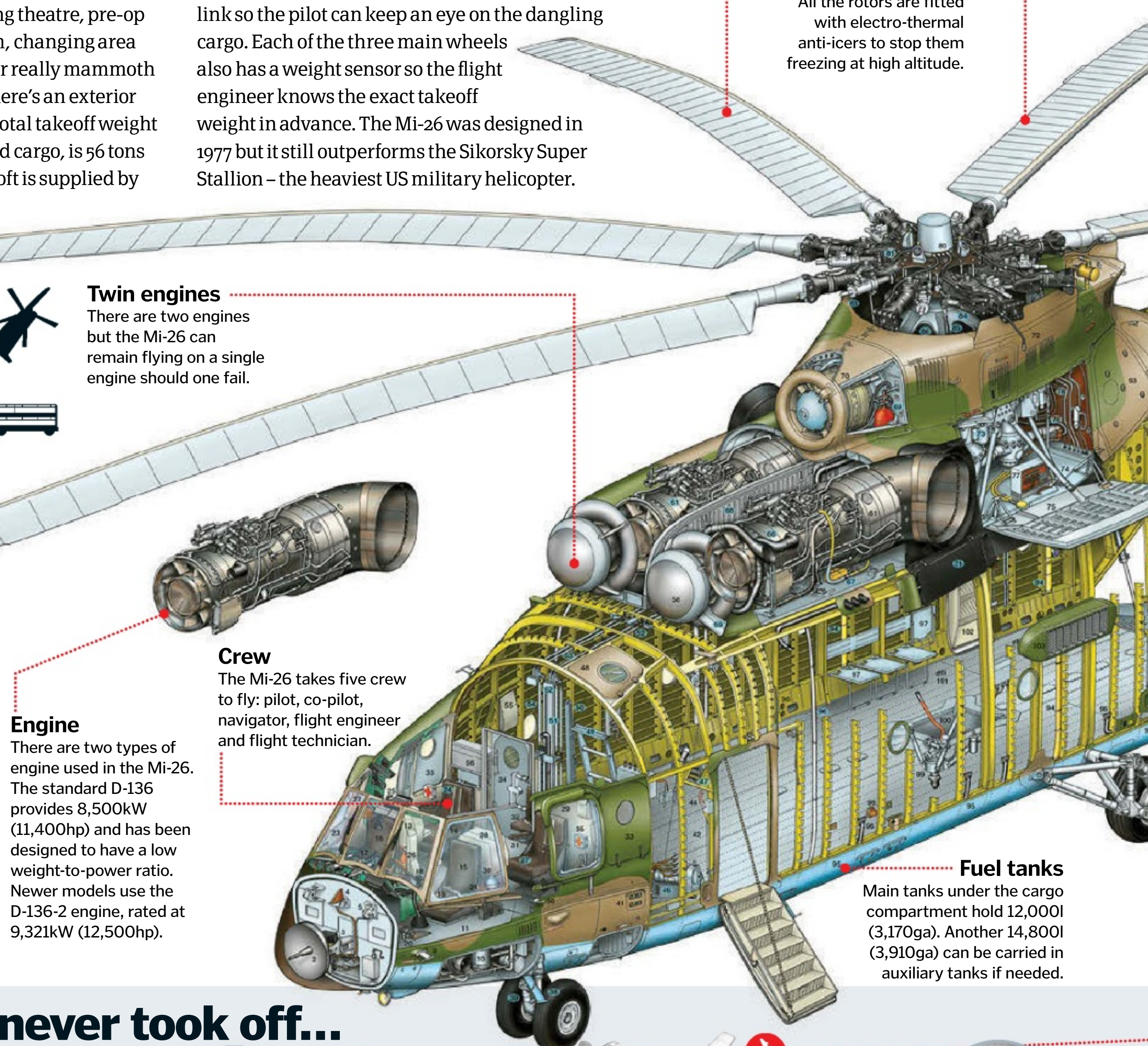
Length: 71.6m (235ft)
Wingspan: 117m (385ft)
Capacity: 226,800kg (500,000lb)
Max takeoff weight: 590,000kg (1.3mn lb)
Range: 1,850km (1,150mi)
Estimated cost: £178mn ($300mn)

"Each of the three main wheels also has a weight sensor so the flight engineer knows the exact takeoff weight"

Mammoth transporter

Mi-26 helicopter

The Russian Mi-26 is the largest helicopter in the world and the one with the greatest lifting capacity. The cargo compartment can fit a fire engine or 150 troops. It can be outfitted as a flying hospital with its own operating theatre, pre-op section, medical lab, restroom, changing area and space for 60 stretchers. For really mammoth loads (see 'Did you know?'), there's an exterior sling rated to lift 20 tons. The total takeoff weight of the Mi-26, including fuel and cargo, is 56 tons and the power to keep it all aloft is supplied by twin turboshaft engines. Lifting such enormous loads needs precision too. The winch mechanism is positioned in line with the main rotor, to avoid unbalancing the helicopter, and includes a video link so the pilot can keep an eye on the dangling cargo. Each of the three main wheels also has a weight sensor so the flight engineer knows the exact takeoff weight in advance. The Mi-26 was designed in 1977 but it still outperforms the Sikorsky Super Stallion – the heaviest US military helicopter.



Eight blades
The Mi-26 was the first production helicopter in the world to use eight blades off a single rotor.

Heated rotors
All the rotors are fitted with electro-thermal anti-icers to stop them freezing at high altitude.

Twin engines
There are two engines but the Mi-26 can remain flying on a single engine should one fail.

Crew
The Mi-26 takes five crew to fly: pilot, co-pilot, navigator, flight engineer and flight technician.

Engine
There are two types of engine used in the Mi-26. The standard D-136 provides 8,500kW (11,400hp) and has been designed to have a low weight-to-power ratio. Newer models use the D-136-2 engine, rated at 9,321kW (12,500hp).

Fuel tanks
Main tanks under the cargo compartment hold 12,000l (3,170ga). Another 14,800l (3,910ga) can be carried in auxiliary tanks if needed.

The statistics...

Mi-26

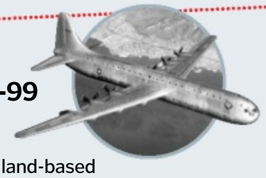
Length: 40m (131ft)
Rotor span: 32m (105ft)
Capacity: 20,000kg (44,100lb)
Max takeoff weight: 56,000kg (123,460lb)
Max speed: 295km/h (183mph)
Cost: £6.5mn ($11mn)

Giants that never took off...

Kennedy Giant 1917
This 8.5-ton British biplane bomber's four engines only had enough power to fly in a straight line. It was cancelled after a single test flight.

Blohm & Voss BV 238 1944
Built by the Germans during WWII, it was a 55-ton seaplane armed with 22 machine guns. The only one built was sunk while docked at Lake Schaalsee, Germany.

Spruce Goose 1947
To save wartime aluminium, this seaplane was built from wood. It was intended as a troop transport but it weighed 113 tons empty and even its 97.5m (320ft) wingspan could barely get it airborne.



Convair XC-99 1947
The largest piston-engined land-based carrier plane ever built. It weighed 61 tons and could carry 45,000kg (99,208lb). Only one was made, but it remained in service for ten years.

HEAD 2 HEAD
HELICOPTER HEAVYWEIGHTS

1. BIG

Hughes XH-17
The Flying Crane was an experimental helicopter built in 1952. It had the largest rotor span ever at 40.8m (134ft).

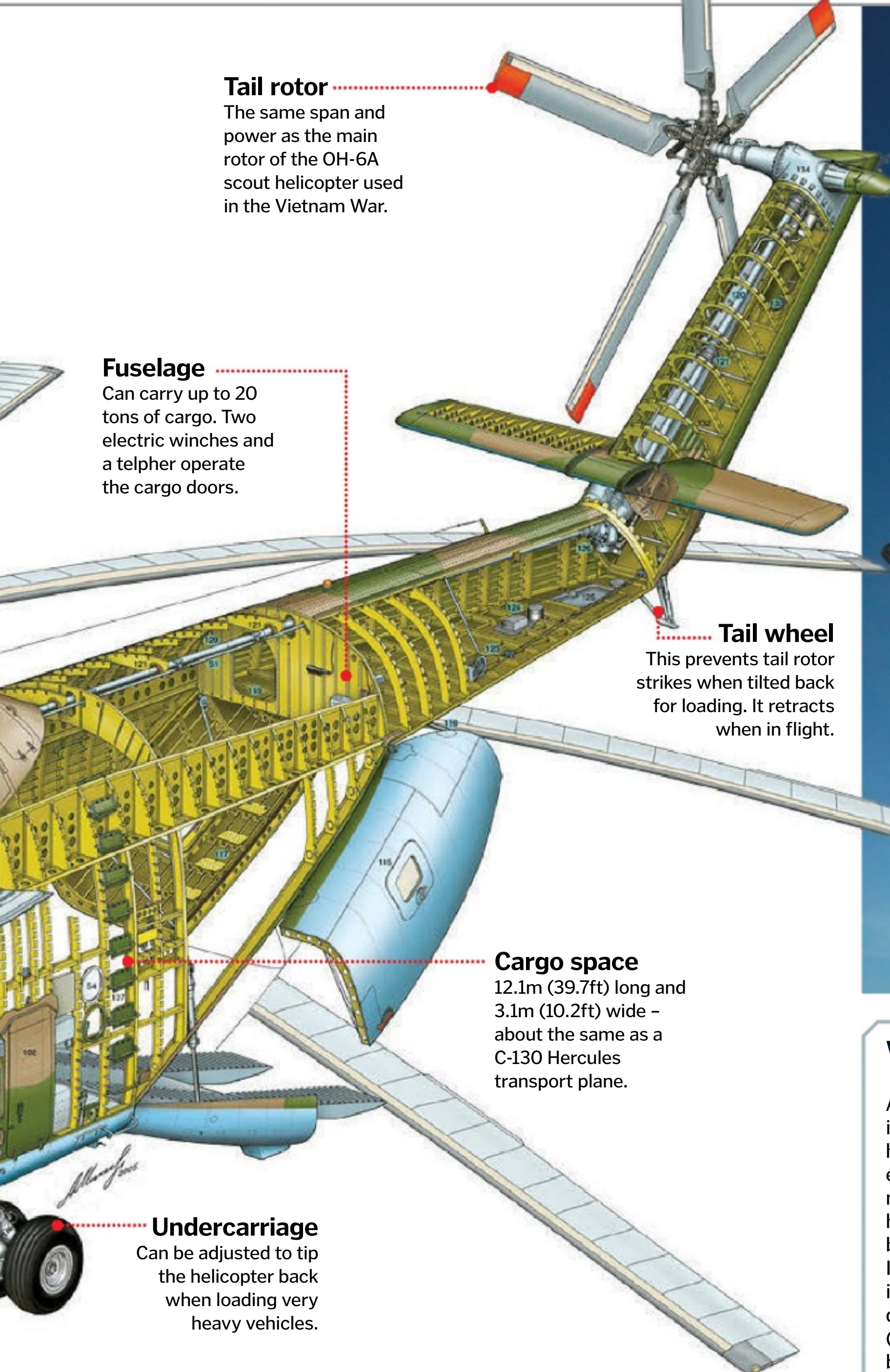
2. BIGGER

Sikorsky CH-53E
The Super Stallion is the largest helicopter in the US military. Lift capacity is 13.6 tons internally or 14.5 tons externally.

3. BIGGEST

Mil V-12
Although it never went into production, the Mil V-12 was the largest helicopter ever to be built. It could lift a mind-boggling 40 tons!

DID YOU KNOW? *In 1999 a Mi-26 was used to carry a 25-ton block of ice containing a frozen woolly mammoth!*



Tail rotor
The same span and power as the main rotor of the OH-6A scout helicopter used in the Vietnam War.

Fuselage
Can carry up to 20 tons of cargo. Two electric winches and a telpher operate the cargo doors.

Tail wheel
This prevents tail rotor strikes when tilted back for loading. It retracts when in flight.

Cargo space
12.1m (39.7ft) long and 3.1m (10.2ft) wide – about the same as a C-130 Hercules transport plane.

Undercarriage
Can be adjusted to tip the helicopter back when loading very heavy vehicles.

A Mi-26 carrying a Tu-134 airliner without breaking a sweat

World's biggest hangars

As you'd expect, the biggest aircraft in the world need the biggest hangars to keep them out of the elements during inspection and maintenance. One of the largest hangars in a commercial airport belongs to the Dubai Royal Airwing. It has space for eight planes, including three Airbus A380s, with doors that are over 580 metres (1,903 feet) wide. The largest building for a single aeroplane, though, is the one-hectare (2.4-acre) Stratolaunch hangar in Mojave, CA.

Once you include airships, the sizes jump way up. The Cardington airsheds in Bedfordshire, used for Airlander, for instance, are 1.4 hectares (3.4 acres) each, while Hangar One at the US Naval Air Station in Sunnyvale, CA, covers 3.2 hectares (eight acres).

The biggest of them all isn't a hangar any more. It was built for the abandoned CargoLifter CL160 airship and you could park the Eiffel Tower on its side within it. It has been turned into a holiday resort.

Bristol Brabazon 1949
A British transatlantic passenger jet. It had a larger wingspan than a 747 and four pairs of contra-rotating propellers. Built for luxury, each passenger had as much space as the interior of a car, which made it hopelessly uneconomical.

Convair X-6 1958
The idea was to mount nuclear-powered engines in a converted B-36 bomber. The plane would have been able to fly continuously for several weeks but the crew required 12 tons of lead and rubber shielding to protect them from the deadly radiation!

Boeing NLA 1993
The New Large Aircraft (NLA) would have seated over 600 passengers, with a maximum takeoff weight of 635.6 tons. However, Boeing abandoned the design to concentrate on 747 derivatives.

Boeing Pelican 2002
This transport design concept could fly like a plane if necessary, but would mostly skim just 6m (20ft) above the surface of the sea. It would have been able to carry around 1,400 tons of cargo.

"Boeing responded by developing the 747-8, which is now the world's longest passenger airliner"

Battle of the airliners

Boeing 747 vs Airbus A380

The Boeing 747 and Airbus A380 are in direct competition for long-haul flights, both for passengers and cargo. When the A380 was first developed, it topped the most common 747 variant, the 747-400, in almost every way apart from price. But Boeing responded in 2008 by developing the 747-8, which is now the world's longest passenger airliner and the heaviest aircraft of any kind to be manufactured in the US. Although it has a smaller passenger capacity than the A380, the gap has shrunk considerably and the 747-8 is lighter, which means it uses less fuel. For airline companies, this makes the 747-8 a considerable 21 per cent cheaper to fly for each trip. However, the A380 is quieter. In fact, it is the quietest wide-body airliner in service, producing only half the noise of a 747 on takeoff. The A380 has also been marketed as more luxurious. The cabin area can be configured with shops, a restaurant and even a beauty salon for passengers. But so far, commercial airline companies have preferred additional seating over luxury and this is still the biggest selling point of the A380.

The statistics…

Airbus A380

Length: 72.7m (238.5ft)

Wingspan: 79.8m (261.8ft)

Capacity: 853 passengers

Max takeoff weight: 560,000kg (1.23mn lb)

Max speed: 945km/h (587mph)

Cost: £240mn ($404mn)

The 747 reinvented

The latest in the Boeing jumbo jet family, the 747-8 has received plenty of upgrades

The statistics…

Boeing 747-8

Length: 76.3m (250.3ft)

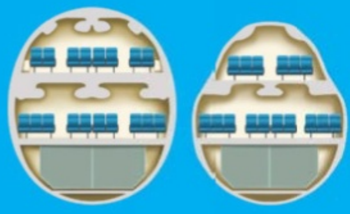
Wingspan: 68.5m (224.7ft)

Capacity: 605 passengers

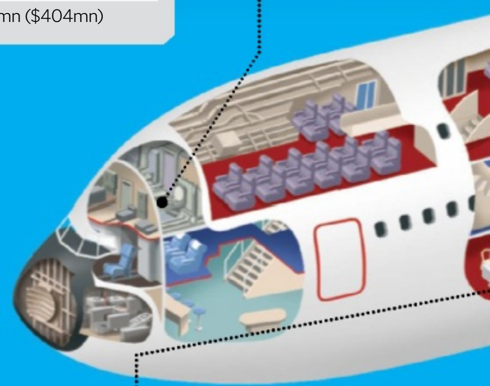
Max takeoff weight: 448,000kg (987,670lb)

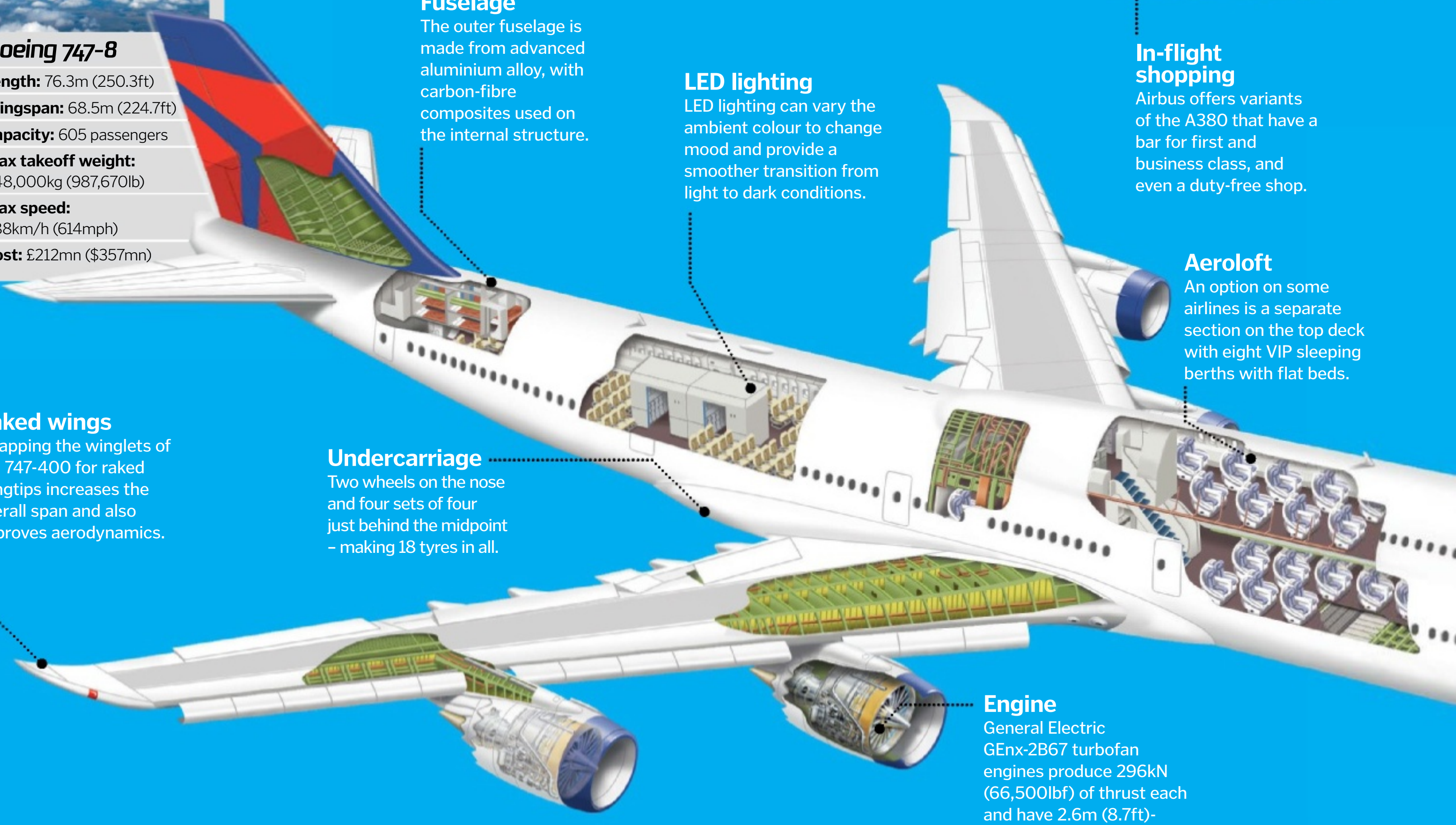
Max speed: 988km/h (614mph)

Cost: £212mn ($357mn)



The inside layout of an A380 (left) and a 747-8 (right)





Fly by wire
The A380 is steered with a computer joystick to the side of the pilot's seat.

Fuselage
The outer fuselage is made from advanced aluminium alloy, with carbon-fibre composites used on the internal structure.

LED lighting
LED lighting can vary the ambient colour to change mood and provide a smoother transition from light to dark conditions.

In-flight shopping
Airbus offers variants of the A380 that have a bar for first and business class, and even a duty-free shop.

Aeroloft
An option on some airlines is a separate section on the top deck with eight VIP sleeping berths with flat beds.

Raked wings
Swapping the winglets of the 747-400 for raked wingtips increases the overall span and also improves aerodynamics.

Undercarriage
Two wheels on the nose and four sets of four just behind the midpoint – making 18 tyres in all.

Engine
General Electric GEnx-2B67 turbofan engines produce 296kN (66,500lbf) of thrust each and have 2.6m (8.7ft)-diameter fans.

297

LARGEST FORMATION SKYDIVE

In 1996, a Mi-26 helicopter was used to set a world record for the largest freefall formation skydive from a single aircraft. The 297 skydivers jumped from 6,600 metres (21,650 feet) up.

DID YOU KNOW? *The Airbus A380 contains a total of 483km (300mi) of electrical wiring*

The flying mall

The A380 is the most luxurious and hi-tech of the wide-body airliners

Elevator

As well as two double-width staircases, there is a lift which connects the decks.

Under pressure

The cabin is maintained at a higher pressure than most airliners – equal to 1,520m (4,987ft) above sea level.

Auxiliary power plant

The computerised electrical power system uses aluminium wiring instead of copper to save on weight.

Control surfaces

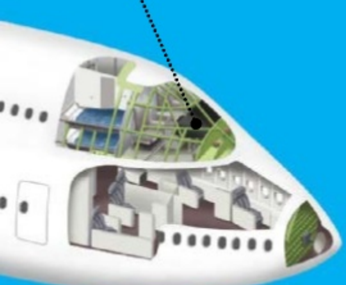
High-pressure titanium hydraulic lines, first used on military jets, save space and reduce weight, thus saving fuel.

Engine

The Rolls-Royce Trent-900 engine produces 320kN of thrust and uses a four-door thrust reverser for braking.

Flight deck

The new flight management computer takes features from the 777 and includes a dedicated central maintenance computer.



Jumbo-sized construction

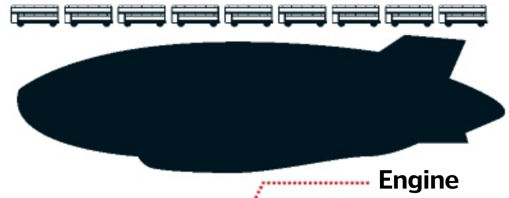
The components for the Airbus A380 are manufactured in plants all around Europe, but they are assembled at a huge 50-hectare (124-acre) site in Toulouse, France, in a process that takes over 1,300 employees just 11 days for each plane.

The three massive fuselage sections travel first by sea, then by barge up the Garonne River, then finally by road. Every two weeks, the road to the Airbus factory is closed overnight so the convoy can pass without holding up traffic.

The fuselage is manoeuvred using giant radio-control motorised scaffolds. The sections overlap along a 12-centimetre (4.7-inch) seam and are held together with 19,000 rivets. Once the wings and undercarriage are on, the airframe is towed to another assembly hangar for the electrical and hydraulic systems to be installed. The engines go on almost last because they are so expensive that Airbus must be sure the plane is almost ready for delivery.

An Airbus A380 being built for Thai Airways

> "Airlander is much quieter and has lower carbon emissions than other aircraft"



15 Olympic swimming pools of helium

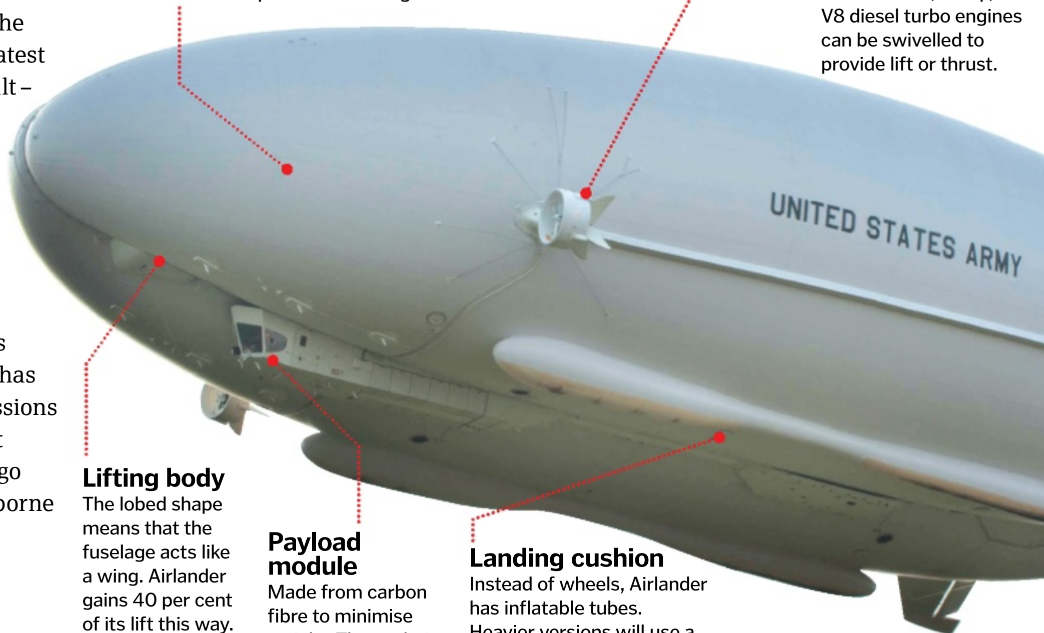
Airlander

Although it looks like a World War II zeppelin, the Airlander is a brand-new design featuring the latest technology. To date the longest aircraft ever built – and with even larger models in development – the 91.4-metre (300-foot) long hull is filled with helium to give it buoyancy. The hybrid lift system means the Airlander can take off vertically and hover, like a helicopter, yet has a range of 4,815 kilometres (3,000 miles). Airlander is much quieter and has lower carbon emissions than other aircraft carrying hefty cargo and it can stay airborne for three weeks!

The statistics...

Airlander

Length: 91.4m (300ft)
Width: 34m (111.5ft)
Height: 26m (85.3ft)
Max payload: 1,225kg (2,700lb)
Max speed: 150km/h (92mph)
Cost: £60mn ($101mn)



Hull
Made from a proprietary three-layer material and filled with low-pressure helium gas.

Engine
Four 261kW (350hp) V8 diesel turbo engines can be swivelled to provide lift or thrust.

Lifting body
The lobed shape means that the fuselage acts like a wing. Airlander gains 40 per cent of its lift this way.

Payload module
Made from carbon fibre to minimise weight. The cockpit at the front needs just two crew.

Landing cushion
Instead of wheels, Airlander has inflatable tubes. Heavier versions will use a hovercraft system to touch down almost anywhere.

An Airlander in its equally giant hangar in Cardington, England

Interview
The future of airships

Chris Daniels from Hybrid Air Vehicles tells us more about the Airlander…

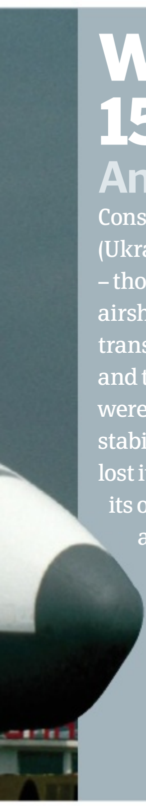
What is Airlander made from?
The hull is made from a specially constructed material that is unique to us. This is based on the materials developed for America's Cup sails and is strong, light and retains its shape. The material consists of three layers heat-welded together: a white outer layer for protection, a weave for strength and a film for helium retention. A strip a few inches wide could easily hold up a family car.

What happens if it springs a leak in flight?
There are separate compartments with valves between them. So if there is a major leak the compartment is isolated. Minor rips and tears don't have much effect as the helium is under such low pressure and there's 38,000 cubic metres (1.3 million cubic feet) of it, so it tends to seep out slowly. Tests on an old [smaller] airship showed it took over an hour and a half for an airship penetrated by 200 large-calibre bullet holes to lose enough helium to [be forced] to land.

How does Airlander cope with bad weather?
Very well. It is designed to be stable and can withstand similar weather conditions to helicopters and other aircraft. On ground, it is designed to withstand 80-knot [148-kilometre/92-mile-per-hour] winds and lightning storms, without damage. Because it's so large, it tends to ride out storms rather than get buffeted by them.

How does its cargo capacity measure up?
The biggest freight aircraft can carry over 100 tons, but they need long runways and are expensive to operate. Airlander can take off and land vertically, and even in a normal 'aeroplane' takeoff it only needs a couple of its body lengths, so it has huge advantages over aeroplanes. We expect to create a 200-ton carrying Airlander, which will be transformational for world cargo.

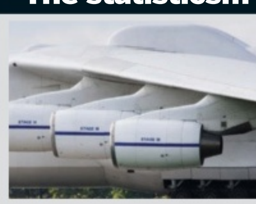
Could we see a return to regular transatlantic passenger trips by airship?
Airlander certainly has the capability. We feel there are opportunities in luxury travel too, opening up some extraordinary ways to do safaris (following animal migrations of caribou, wildebeest or whales) and getting to amazing locations that are otherwise difficult [to access].



Weighs the same as 157 London taxis
An-25 Mriya

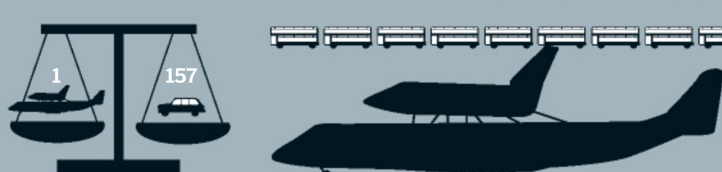
Constructed in Ukraine in 1988, the Antonov An-225 Mriya (Ukrainian for 'dream') still holds the record of heaviest-ever plane – though its length record has now been claimed by the Airlander airship. This cargo transporter had one primary purpose – to transport the Buran space shuttle. The shuttle weighed 170 tons and the An-225 acted as its airborne launch platform. Launches were possible at heights of up to 10,000 metres (33,000 feet) and its stabilising split tail increased manoeuvrability. The An-225 Mriya lost its role after the USSR collapsed. NASA used it as a template for its own shuttle launches using modified Boeing 747s and rumours are circulating that the European Space Agency may be bringing it back for future space missions.

The statistics…



An-225 Mriya

Length: 84m (276ft)
Wingspan: 88.4m (290ft)
Height: 18.1m (59ft)
Weight: 285,000kg (628,317lb)
Max speed: 850km/h (528mph)
Maximum takeoff weight: 600,000kg (1.32mn lb)
Max range: 15,490km (9,625mi)



RECORD BREAKERS
ONE-WHEEL WONDER

84km/h

FASTEST-EVER MONOCYCLE

In 2013, Tom Anable smashed the British record for the fastest speed recorded on a monocycle, with his confirmed 84km/h (52.5mph) more than doubling the previous record set at 38km/h (23.5mph).

DID YOU KNOW? *If braking resulted in a greater force than gravity, the driver could easily spin around like a hamster in a wheel*

Monocycle mechanics

With only one wheel on the ground, this bizarre vehicle can make for an exciting – if precarious – way to get around

A one-wheel motorcycle, otherwise known as a monocycle, is a vehicle where the driver is seated upright inside a large wheel frame made from an alloy. This wheel frame spins the larger outer wheel, which comes into contact with the floor and usually has a tyre mounted to it. The outer wheel is typically spun via smaller wheels attached to the inner frame of the monocycle.

Although small petrol engines are most commonly used on monocycles today (mounted within the frame), there are also non-motorised versions around, typically called monowheels, where the rider is propelled along via pedals, a chain and plenty of good old-fashioned leg work! Due to the precariously balanced nature of the vehicle, even motorised monocycles can generally only reach top speeds of around 40 kilometres (25 miles) per hour.

Steering is usually executed via the driver leaning from side to side, though it can prove difficult to corner smoothly while remaining balanced. If the driver drags a foot, this will cause friction, slowing down one side of the monocycle and providing a tighter turning circle for better cornering.

However, there are several fundamental drawbacks associated with riding a monocycle. Maintaining a consistent balance in a one-track vehicle with only one point of contact to the ground presents obvious reservations over stability. Visibility is another issue; with the driver sitting inside the wheel, the view straight ahead is severely restricted.

The limited capacity (monocycles have only ever been successfully designed for single occupancy) could be another reason why it's never really taken off as a widespread mode of transport.

US inventor Kerry McLean has been designing and riding monocycles for decades

Evolution of one-wheelers

The concept of the monocycle was originally born in Marseilles, France, in the 1860s thanks to a craftsman by the name of Rousseau. His idea incorporated a unicycle inside a wheel some 2.3 metres (7.5 feet) high. Monocycles would remain pedal-powered until the turn of the 20th century. Engines were then mounted onto the inner wheel frame, directly under the driver's seat, and the former handlebars acquired finger throttles for speed control.

Perhaps the most radical modern-day evolution comes courtesy of the RYNO monocycle (inset). Here, the driver sits on top of the wide single wheel and motor, as opposed to the more conventional McLean monocycle where the driver and motor sit inside the wheel (left). Looking like a cross between a Segway and a motorcycle, the RYNO uses self-levelling technology to ensure the vehicle stays balanced and it runs off rechargeable batteries, so it's fairly eco-friendly too.

Monocycles in the movies

1 Men In Black 3
The iconic alien-busting trilogy starring Will Smith has provided an eclectic mix of tech-laden gadgets, and the final instalment includes a stint where Agents J and K use futuristic monocycles to navigate the city.

2 Teenage Mutant Ninja Turtles: Fast Forward
The pizza-loving reptiles get thrown forward to 2105 in a time machine. As expected, tech has advanced and their main form of transport is the monocycle. Each turtle sits inside the wheel which rotates around them, but leaves them steady to steer and fire missiles.

3 Star Wars
General Grievous is seen riding a mean-looking twin-track monocycle – complete with gun mounts – in *Episode III: Revenge Of The Sith*. It appears in a chase scene with Obi-Wan Kenobi.

4 Spiral Zone
The American sci-fi series from the late-1980s features a monocycle being used by Commander Dirk Courage, who also has a large cannon attached to the vehicle.

5 Yu-Gi-Oh!
In *Yu-Gi-Oh! 5D's*, the third instalment of the Japanese anime franchise, a monocycle is frequently used in duels by character Jack Atlas, who affectionately calls it the 'Wheel of Fortune'.

"If you veer too close to one side, the camera registers this and sends a signal to your steering wheel"

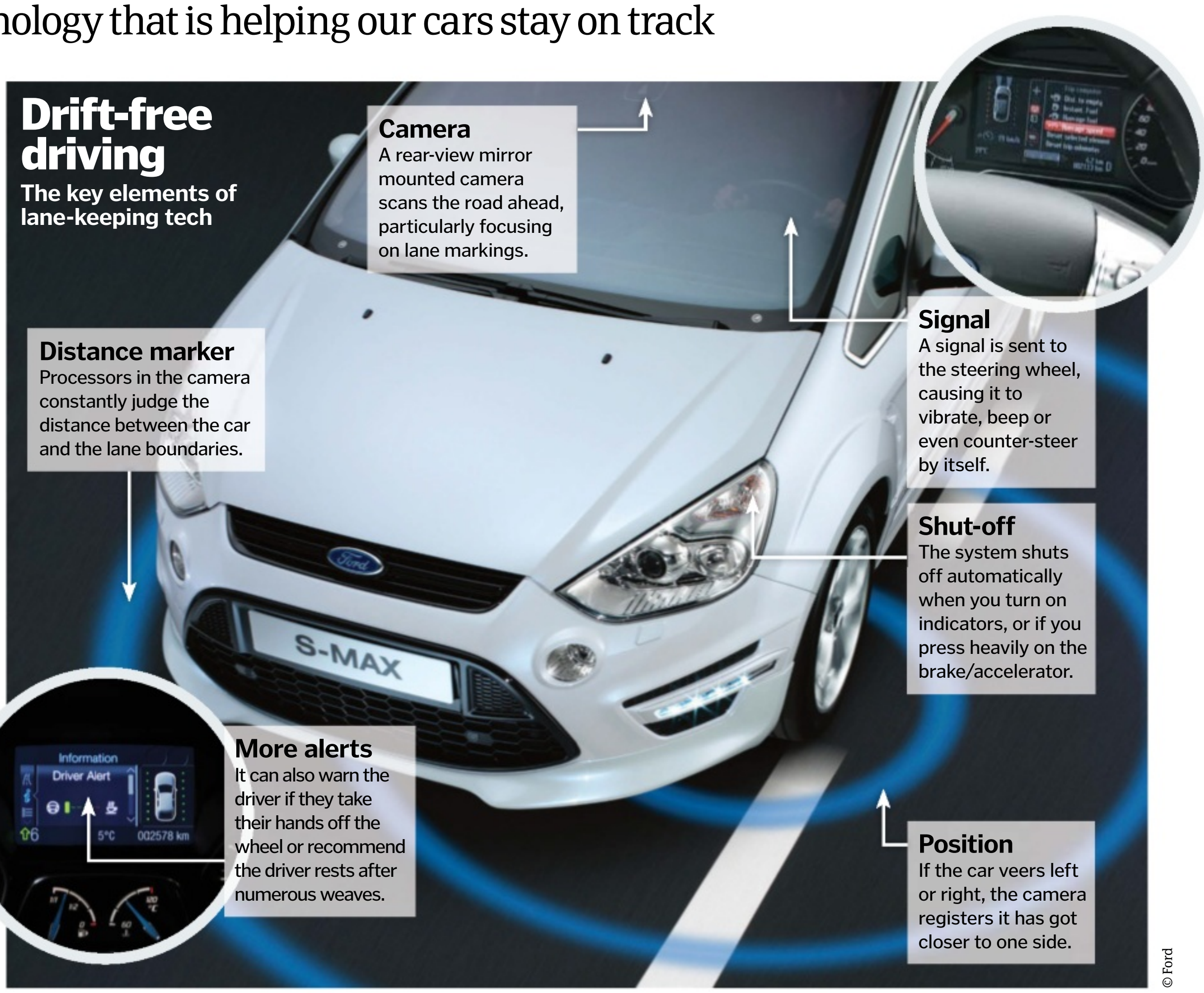
Automatic lane keeping

Discover the new technology that is helping our cars stay on track

In a recent study, 37 per cent of Americans and ten per cent of British drivers admitted to falling asleep behind the wheel. This worrying statistic has prompted car manufacturers such as Ford, BMW and Toyota to develop innovative lane-keeping technology in an attempt to avert potential accidents.

This involves mounting a camera on your windscreen or rear-view mirror that monitors the gap between your car and the white lines that mark the extremities of the lane. If you begin to veer too close to one side, the camera registers this and sends a signal to your steering wheel, which will vibrate to alert you of your movement or emit a warning beep. Some systems also provide counter-steering to help you recover your position.

The warning system will be temporarily shut off when you are indicating so as to avoid being an irritant while turning or overtaking on a motorway.



© Ford

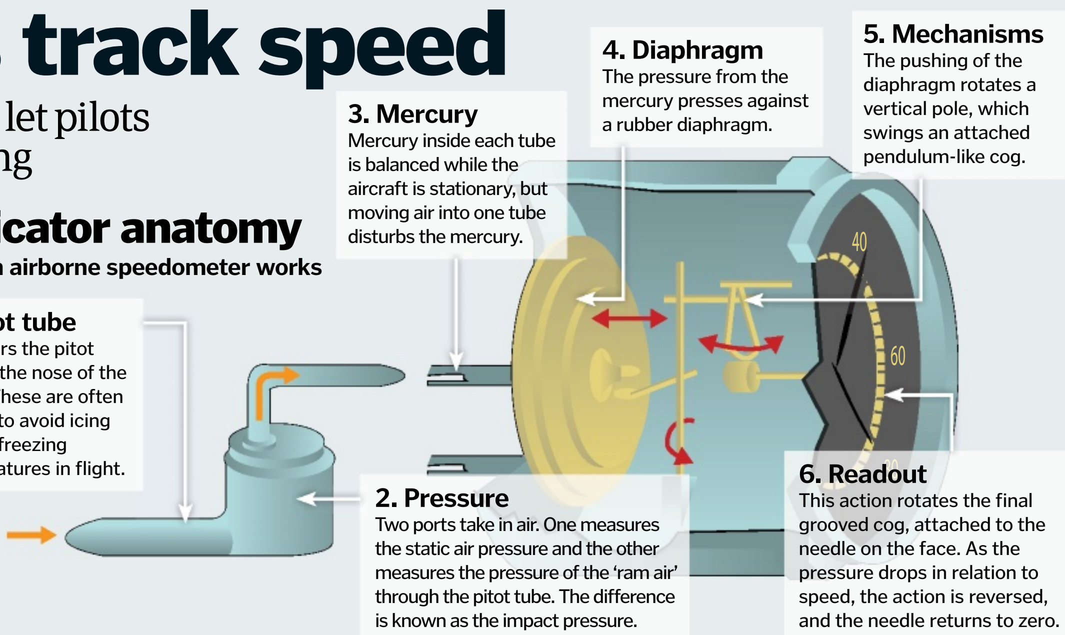
How planes track speed

Inside the instruments that let pilots know how fast they are flying

It's easy to know how fast you're going in a car by measuring how quickly the wheels are turning, but what if you're travelling off the ground? As airspeed is essential knowledge for pilots, the airspeed indicator is a key piece of tech in the cockpit. It works by measuring the pressure difference between a tube with air rushing through it and one without air rushing through it, and using that data to move the needle or produce a digital readout.

Indicator anatomy

How an airborne speedometer works



Game changer

The new Mitsubishi Outlander PHEV.

If you believe the hype, every new car is a game changer. A degree of scepticism about yet another worldbeater is therefore understandable.

Don't ignore the Outlander PHEV, though. This one really is a game changer.

A few Outlander PHEV facts:
Price: from £28,249 (post-grant)
Benefit in Kind tax rate: 5%
Vehicle Excise Duty: £0
London Congestion Charging: £0
CO_2 emissions: 44g/km
Pure EV range: 32 miles
Pure EV + Petrol range: 514 miles

They look like stats for a tiny city car ten years in the future, but the Outlander PHEV achieves these figures now, in 2014. And it does so as a lavishly-equipped SUV with no restrictions on interior or boot space. For company car user-choosers, the benefits of running an Outlander PHEV are startling. BIK and fuel card tax ratings are just 5% rather than the expected 30%-plus for equivalent diesel SUVs.

For any driver, Outlander PHEV fuel consumption is incredible. The official EU figure is 148mpg, but if your daily journey is less than 32 miles it could be considerably more. Longer journeys like motorway trips can still return impressive figures. Unlike the average electric vehicle, there's no danger of 'running out of juice' as long as you've got some petrol in the tank, and this is the only SUV with '£0' on the tax disc.

Here, at last, is a hybrid car that really does offer ultra-cheap motoring without compromise to comfort, practicality or performance – and without the dreaded EV 'range anxiety'.

How does it do it?

The PHEV was designed from the outset to run on electric power. That's why, unlike just about every other EV, it has uninterrupted cabin and boot space. Its 463-litre cargo volume is almost identical to the diesel Outlander's.

There's a conventional engine up front, a refined, quiet and lightweight 2.0-litre petrol unit, but after that everything changes. The engine's main role is not to drive the car, but a generator. This charges an array of underfloor batteries powering two direct-drive electric motors: one on the front wheels, the other on the back. As long as there's sufficient charge in the batteries, the electric motors will work alone at speeds up to 75mph.

If the engine does need to kick in to top up the batteries, it will, but the transition between electric and petrol is all but undetectable. No allowances need to be made to your driving style: the car will always choose the most efficient mode. Generally, that will be EV mode at lower speeds, and electric motors supported by the engine at higher speeds. You can dial up a higher rate of battery regeneration by flipping a steering wheel paddle to recoup more power during deceleration, which brings the bonus of reducing brake wear.

In every other respect, driving a PHEV is exactly like driving a normal SUV, albeit a very comfortable, safe (5-star Euro NCAP rated) and powerful one. From 0-60mph it's quicker than the already rapid 2.2 diesel auto Outlander, with the instant shove of electric power.

You can charge the car by plugging it into a high-speed charger (installed for free* at your house by British Gas), or let it look after its own charging through normal driving. If you're going somewhere where the ability to run on EV power would be useful, you can charge the batteries to 80% capacity in 30 minutes just by letting the engine idle. You can even remotely control the charging process (and pre-heat or pre-cool the vehicle) through a free-to-download iOS or Android app.

From a full charge, which takes 3-4 hours from zero (using cheap Economy 7 electricity if you do it overnight), the Outlander PHEV will run for up to 32 miles on electric power alone. So, if your total daily journey is less than 30 miles (which most are) you could find yourself never using the PHEV's petrol engine. If you are an 'electric-only' user, the engine stays in good health by starting itself up every now and then.

The best thing about this extraordinary machine is just how ordinary it is in everyday use. Being a Mitsubishi, it's a proper offroader running a Super-All Wheel Control (S-AWC) permanent 4WD system with a lock mode for the really gooey stuff. The PHEV handles surprisingly well too, thanks in part to the batteries' underfloor location lowering its centre of gravity. Towing capacity is an impressive 1500kg. You won't have to search out specialists to service it, as you do for many other EVs. Any Mitsubishi dealer can deal with it.

The price.

Electric vehicles and hybrids are expensive, even after you take into account the Government's £5000 Plug-In Car Grant but the Outlander PHEV is very different. It was designed from day one to be an EV, so there's no hybrid price premium. Higher-specified GX4h and GX4hs versions are also available, but let's look at the GX3h version.

The cost of a GX3-spec diesel Outlander 2.2 DI-D Auto is £28,249. After the Government grant, the cost of the equivalent GX3h PHEV – with automatic gearbox, remote-controlled keyless entry, leather-wrapped steering wheel and gear knob, cruise control, dual-zone climate control, automatic headlights and wipers, electric windows, 18-inch alloy wheels, roof rails, rear privacy glass, USB port, iPod compatibility and Bluetooth connection – is also £28,249.

Which may very well be the most exciting motoring news of the year, if not the decade.

*Subject to survey

Outlander PHEV range fuel consumption in mpg (ltrs/100km): Full Battery Charge: infinite, Depleted Battery Charge: 48mpg (5.9), Weighted Average: 148mpg (1.9), CO_2 Emissions: 44 g/km.

Pop in and see your local dealer for more information or visit
www.mitsubishi-cars.co.uk

MITSUBISHI MOTORS

"Nicolaus Otto built the first practical iteration of the design and fitted it to a motorcycle"

How four-stroke engines work

Learn about the four simple steps used to generate power and get our vehicles moving

Put simply, four-stroke engines generate power by initiating controlled explosions that provide movement. In the case of a motor vehicle, most of which use four-stroke engines, these controlled explosions produce kinetic energy to turn the wheels, propelling the vehicle.

The explosions are initiated by igniting, combusting and expanding a fuel and air mixture during a four-step process: intake, compression, power and exhaust (or more commonly 'suck, squeeze, bang, blow').

The four-stroke engine (sometimes called the Otto cycle engine) was invented in 1876 when Nikolaus Otto built the first practical iteration of the design and fitted it to a motorcycle. This was seen as the first major alternative to the contemporary steam engine, and the engineering concept has undergone many evolutions since, incorporating different fuels and even combining with other energy sources in hybrid vehicles, such as hydrogen.

Today, four-stroke engines are still the most common type of internal combustion engine used for transport as they offer a smooth ride, produce less pollution than many alternatives and are much more efficient and powerful than a two-stroke or rotary engine. Going against them however, four-stroke engines can be complicated to manufacture and repair in the event of malfunction, as there are so many components that go in to the system.

Engine efficiency in focus

Engine efficiency is the transfer of readily available energy from a fuel into usable power output from an engine consuming that fuel. Engine efficiency is measured by dividing the output energy by the heat lost. Most petrol internal combustion engines actually have a low efficiency – usually in the region of 20-25 per cent.

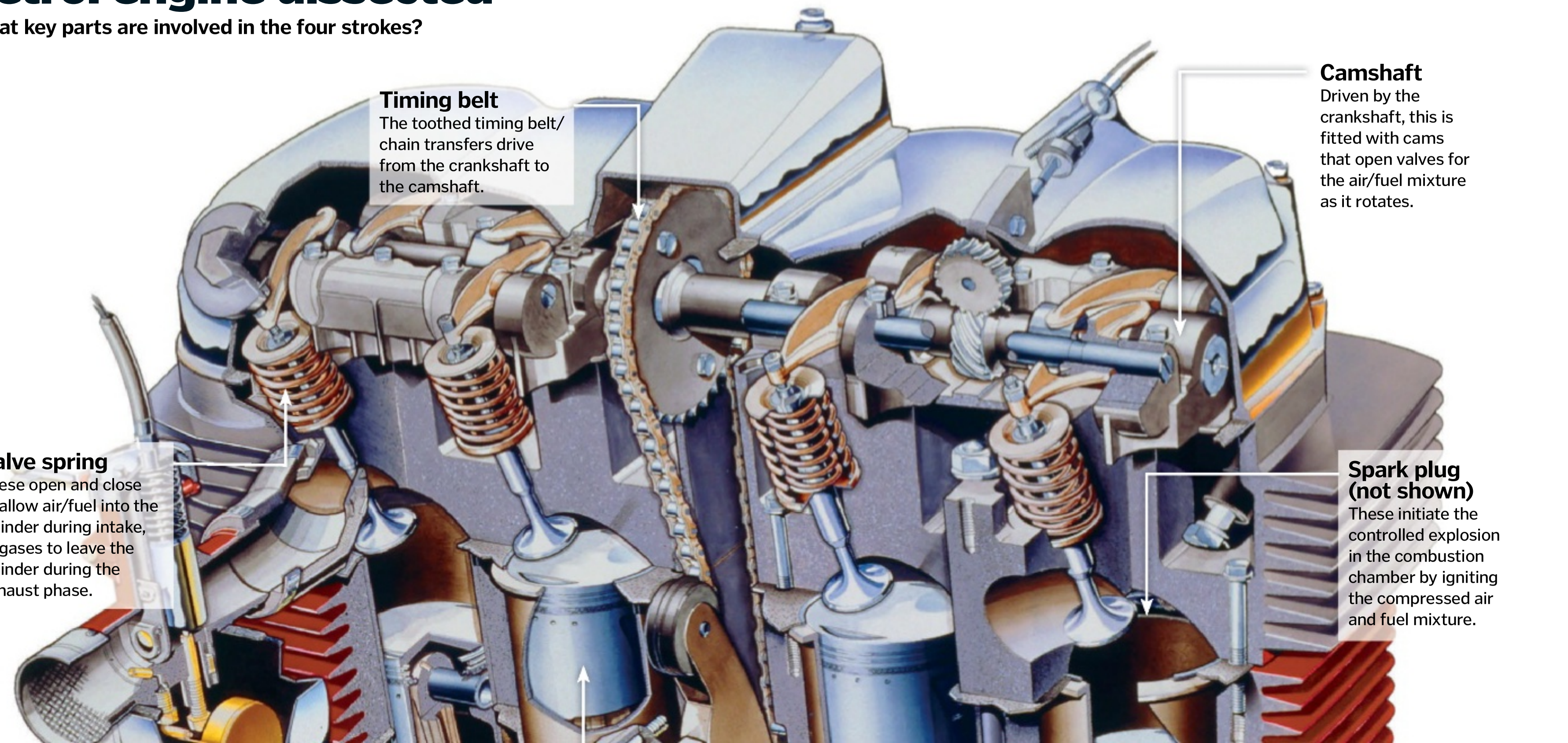
The better the efficiency, the lower the fuel consumption, reducing emissions. This also makes for a reduction in taxes as pollutant output has been cut.

Key factors that dictate engine efficiency are heat and friction. As a result, engines use a variety of components to try and counter these problems. For example, oil is used to help reduce the friction between moving parts in an engine, while a radiator helps to keep the water running through an engine cool. Vehicles also have a cooling fan for the engine compartment, which is activated when operating temperatures become too hot.

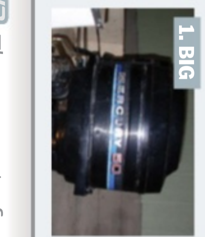
As technology has evolved, engine efficiency has improved. For example, turbocharged engines utilise a front-mounted intercooler to keep heat down while driving.

Petrol engine dissected

What key parts are involved in the four strokes?



1. BIG



Inline four

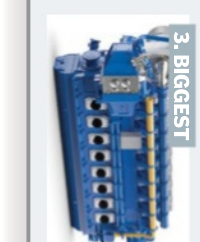
The engine used to power light motorboats like the Mercury Bigfoot 50 has four cylinders and produces 50bhp – high power for a unit weighing just 118kg (260lb).

2. BIGGER

4.2-litre V10

While most four-stroke engines have four cylinders, supercars have much larger powerplants. The new Audi R8 has ten, generating a cool 550bhp.

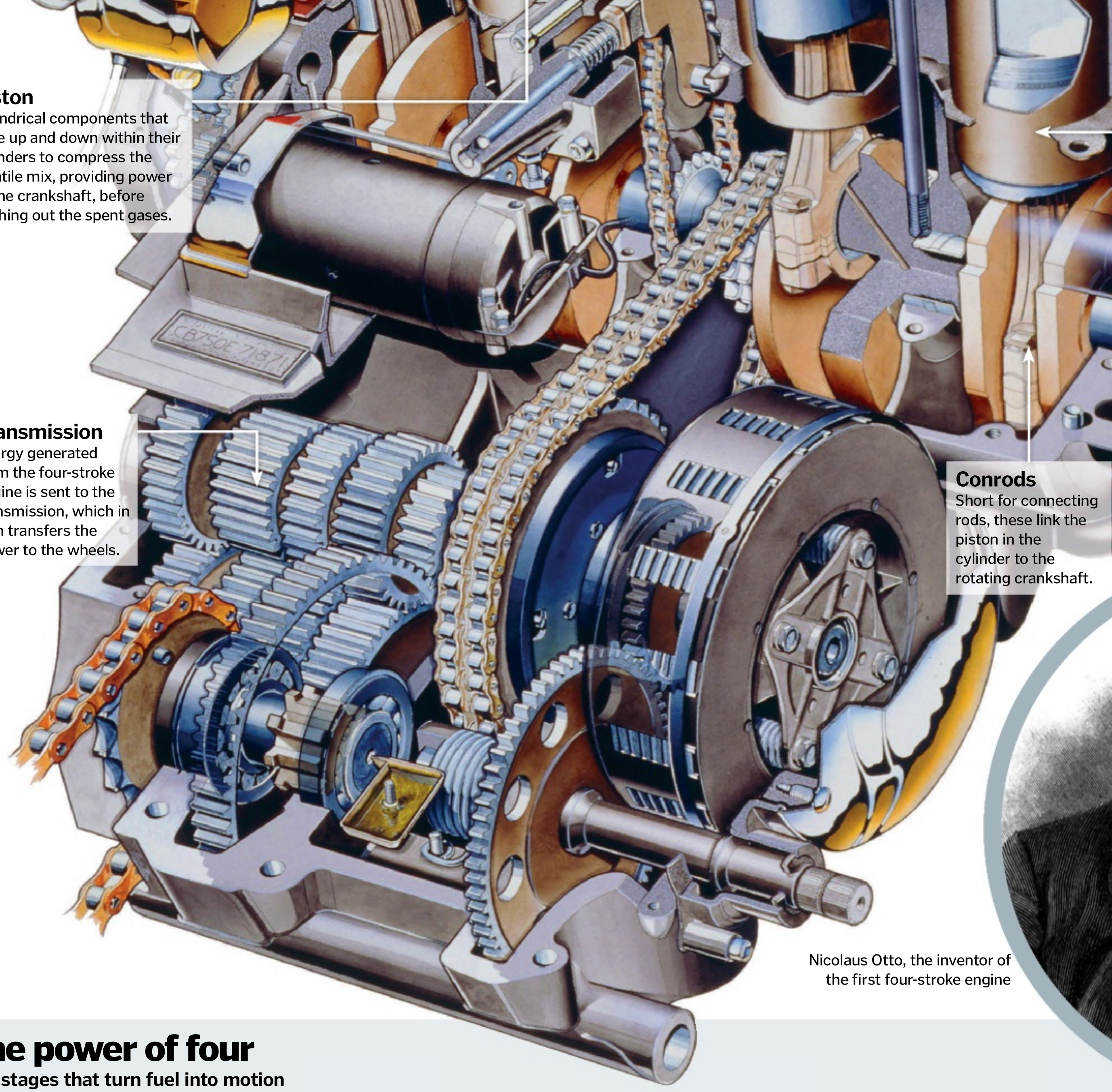
3. BIGGEST



18-cylinder Wärtsilä

One of the world's biggest four-stroke engines is the Wärtsilä 18V46 designed for marine vessels, producing 1,500bhp per cylinder!

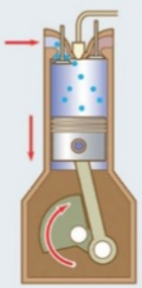
DID YOU KNOW? *The amount of air and fuel mixed for compression is adjusted by a vehicle's engine control unit (ECU)*



Nicolaus Otto, the inventor of the first four-stroke engine

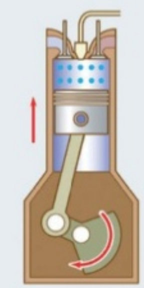
The power of four

The stages that turn fuel into motion



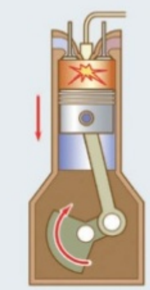
1. Intake

As the crankshaft turns and the piston moves down the cylinder, the fuel/air mixture is drawn in through the inlet valve (top left). When the piston has reached the bottom, the cylinder is filled with the fuel/air mixture, and the inlet valve closes.



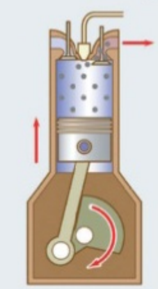
2. Compression

With both valves at the top of the cylinder closed, the crankshaft moves the piston upward, compressing the mixture inside the cylinder (the combustion chamber), increasing its temperature very quickly. When the piston reaches its highest point, the mixture is fully compressed.



3. Power

With the mixture under great pressure and temperature, all that's needed to ignite it is a spark. This is provided by the spark plug, and the resulting controlled explosion is powerful enough to force the piston down to the bottom of the cylinder again, pushing the crankshaft around.

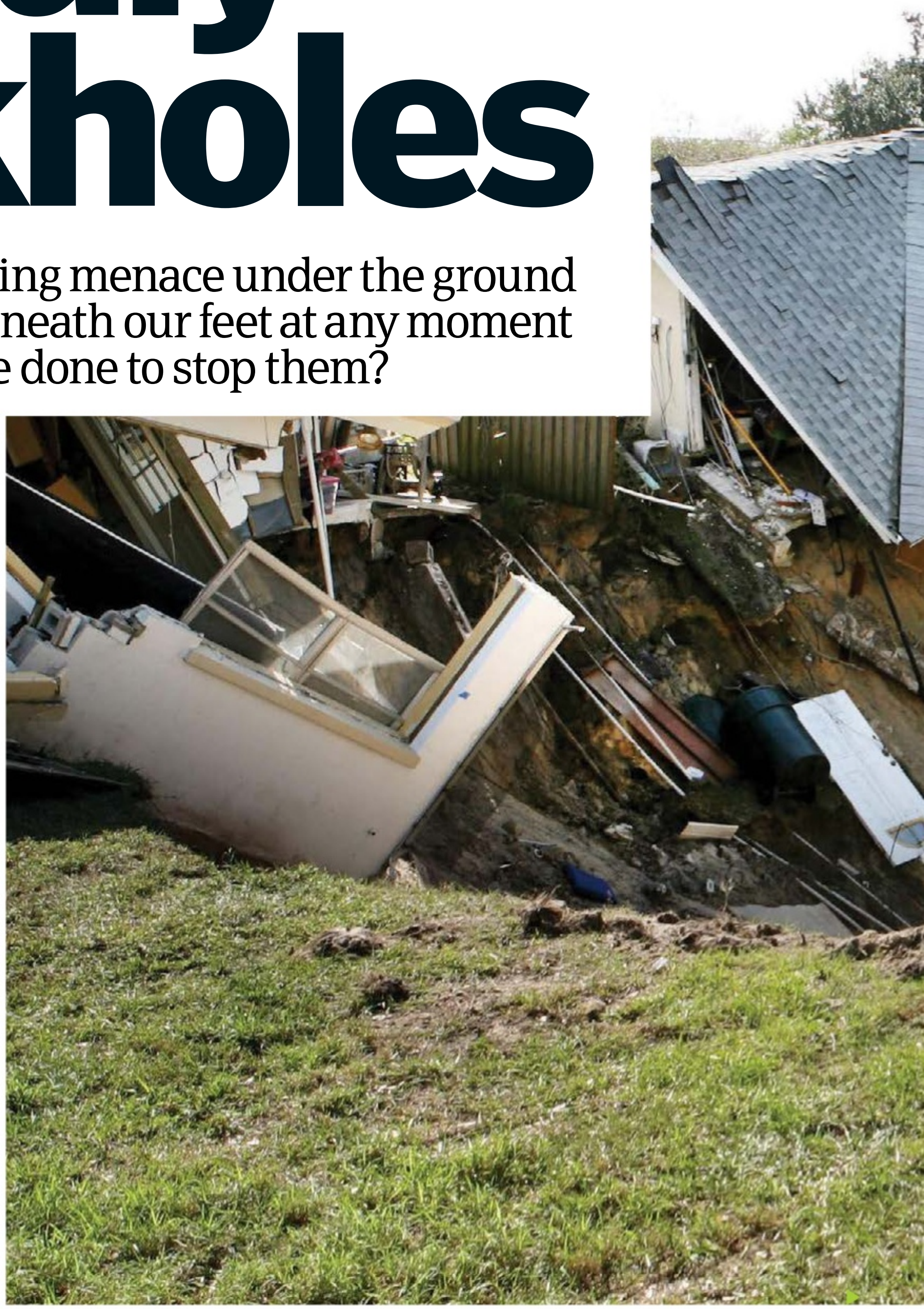


4. Exhaust

As the crankshaft rotates and pushes the piston back up inside the cylinder, the exhaust valve opens at the top to allow the burnt exhaust gases to escape. With the piston back at the top of the cylinder, the exhaust valve closes and the four-stroke cycle starts over.

Deadly sinkholes

What causes this lurking menace under the ground that could open up beneath our feet at any moment – and can anything be done to stop them?



In March 2014, a huge hole suddenly opened up in a road intersection in the city of Detroit in the United States. It was nine metres (30 feet) wide and five metres (16 feet) deep. This is a type of geohazard known as a sinkhole. They are the result of unstable cavities in the ground, which are created from soluble bedrock dissolution caused by a change in underground moisture content and water levels. Because of this, these massive pits more commonly appear in the calendar's wetter months. The effect is exaggerated even more when sudden flooding follows a drought as the ground is not saturated and cannot handle the unexpected deluge.

The most common rocks where sinkholes form are limestone, chalk and gypsum – all of which are soluble sedimentary rocks. These minerals are found in the overburden soil that covers caves, ravines and streams – topography known as karst. Chalk and limestone are two of the most common rocks in the world, so sinkholes can virtually open up anywhere.

The places most at risk on Earth are Florida, South Africa and the cave systems of the Mediterranean. In the United Kingdom, the Peak District, Yorkshire and, more recently, the south-east of England are all danger zones.

Dr Vanessa Banks, a hydrogeologist at the British Geological Survey (BGS), claims that the unusually high amount of rainfall in Britain in the winter of 2013 contributed to at least 19 collapse features in Britain in February 2014. The fact that normally only ten or so sinkholes

AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

Check out the Winter Park sinkhole in Florida!

www.howitworksdaily.com

DID YOU KNOW? 24,671 insurance claims for sinkhole damage were registered in Florida between 2006 and 2010

"Collapses can either be instant or slow-forming, depending on the material on the surface"

are reported to the BGS each year shows the adverse effect that the weather had on the British Isles last winter.

As well as the initial effects, which can include vehicles or entire buildings being swallowed up, there can be a number of long-term consequences. Sinkholes can cause flooding by blocking underground water flow – and in extreme cases this can transform previously dry land into bogs and even lakes.

One of the largest sinkholes ever recorded was the so-called Winter Park sinkhole in Florida that appeared in 1981. It caused mass devastation, swallowing two streets of buildings and cars, amounting to over £2.4 million ($4 million) worth of damage. It spanned a massive 107 metres (350 feet) across and 23 metres (75 feet) deep.

Sinkholes can be split into three varieties: subsidence, solution and collapse. Subsidence holes are created when the overburden is thin and only some sediment is above the carbonate rock. Solution is where there is no overburden layer and collapse is when the permeable rock is weighed down by a huge mass of residue.

Collapses can either be instant or slow-forming, depending on the material on the surface. If the covering material is noticeably light and weak – such as sand – small, gradual fissures are formed over time, while if the surface material is denser – like clay – there is more pressure and weight so it will cave in more suddenly. Generally, if it is the roof of an underground cavern falling, the holes are deeper and steeper, while if it is the dissolving of rock under a soil mantle, they tend to be considerably shallower.

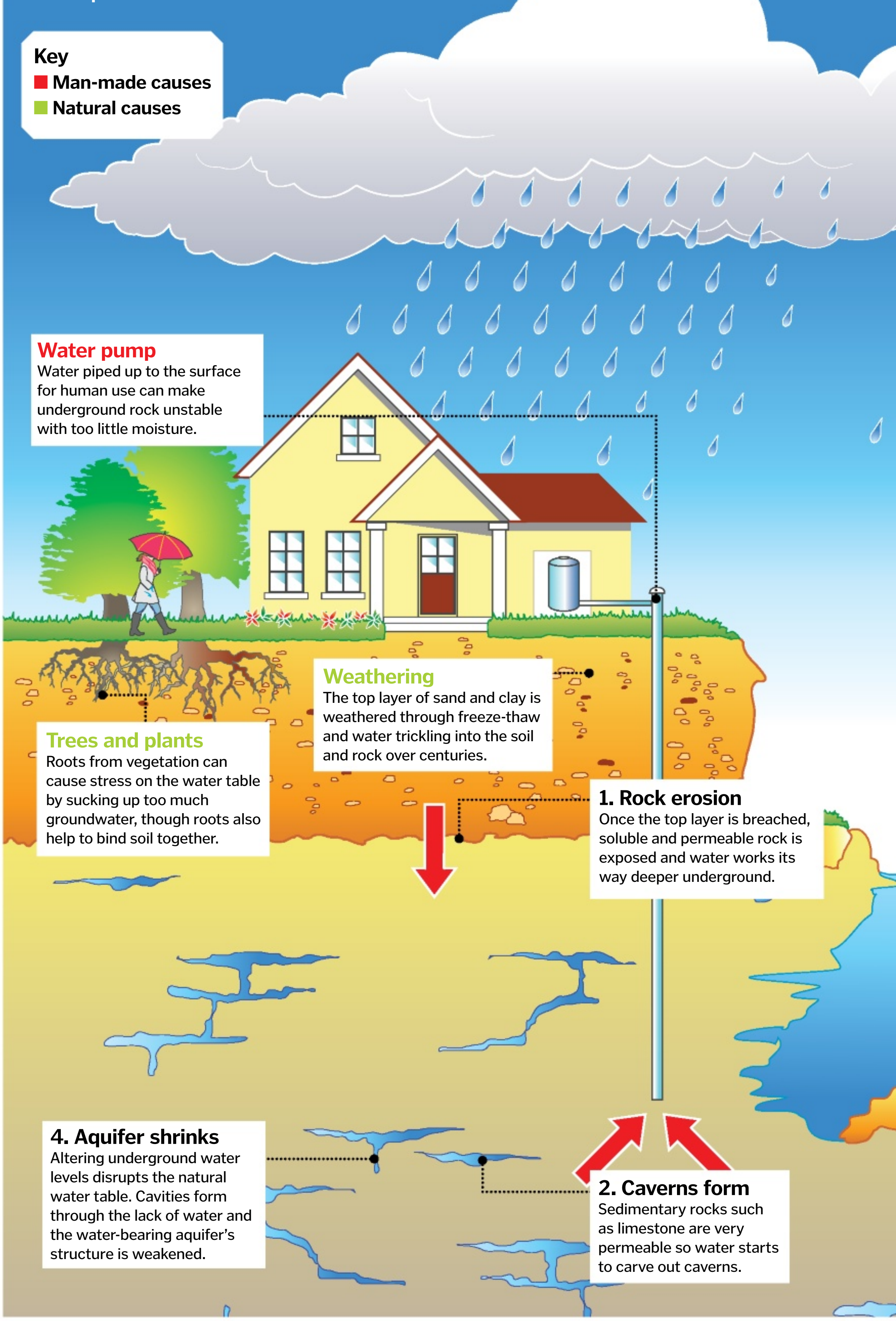
While sinkholes are defined as a collapse over a void of soluble rock, deneholes or 'crown holes' differ. These occur when there is an overburden breakdown over a modern man-made mine, such as a shaft collapse.

As the Winter Park example shows, not all sinkholes occur in the wilderness, with holes evermore frequently opening up in urban areas. The disturbing of groundwater by man-made devices and mechanisms leads to more intense and devastating sinkholes. By altering the natural path of ground water – for instance, in irrigation – we run the risk of exposing soluble rock to more liquid than it can take. In contrast, taking away water for human consumption can open up cavities in the ground and weaken natural foundations.

Above-ground vibration from busy roads and building work can also have a big impact on the

Sinkholes: who's to blame?

Check out the man-made and natural culprits and the process which leads to sinkholes

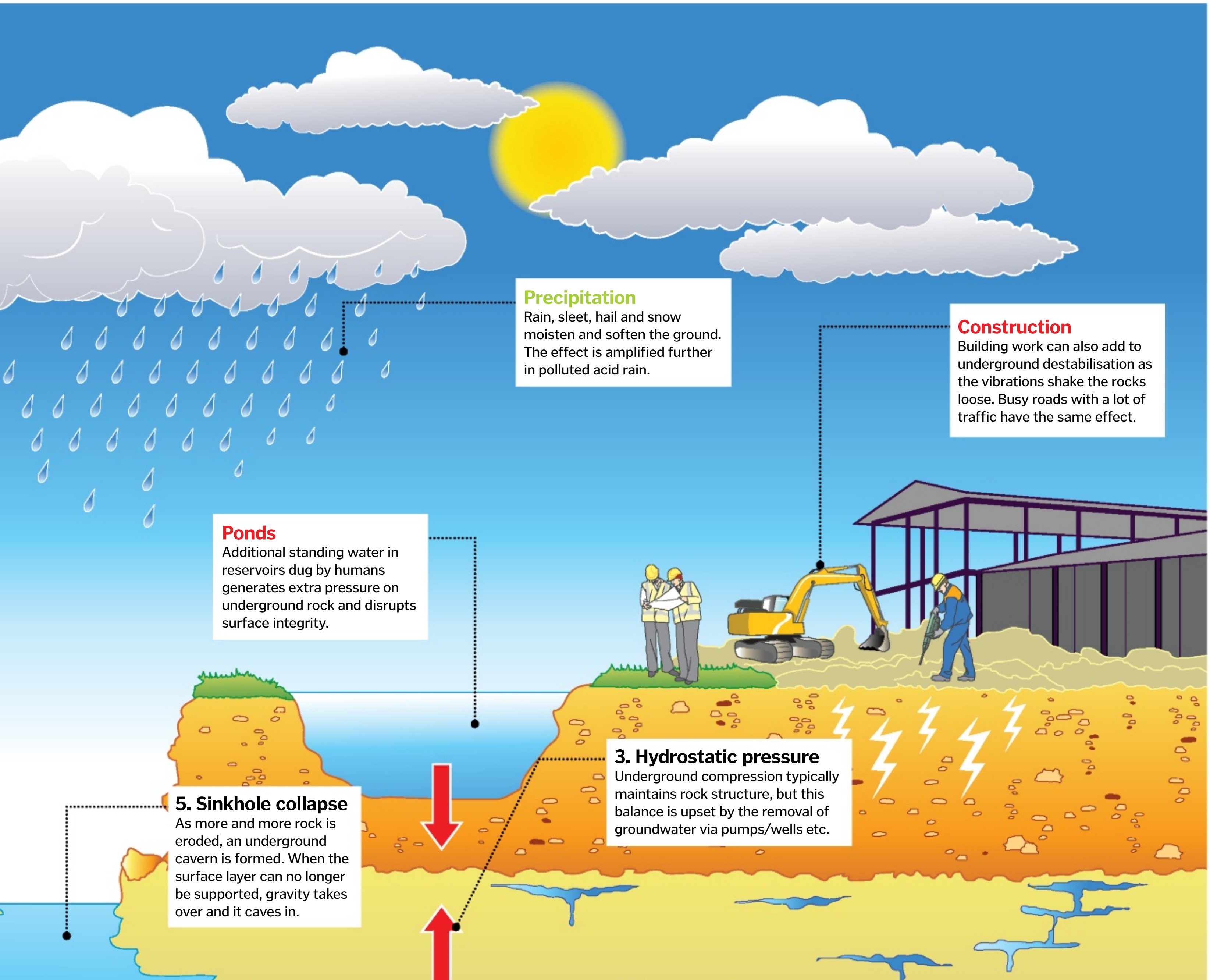


What is the Bimmah sinkhole in Oman used for?

A Landfill **B** Astronomy **C** Tourist spot

Answer:
Often portrayed as a natural menace, swallowing cars and buildings whole, the Bimmah sinkhole in northern Oman is a popular tourist attraction within the Hawiyat Najm Park, where many visitors come annually for swimming and camping.

DID YOU KNOW? *Around 20 per cent of the USA lies on karst areas, which are susceptible to sinkholes*



Hunting for sinkholes

How can we spot potential holes before it's too late?

To assess sinkholes, various state-of-the-art techniques are used. 2D electrical resistivity imaging involves electrical currents analysing the hydrogeology of areas. Using electrodes and ground-penetrating radar (GPR), the resistivity of the ground is measured. This creates an image that shows not only the subterranean structure, but also its pores and moisture content. 3D techniques are also employed to result in a better, more accurate image. Another type of imaging system is microgravity imaging. This technique detects tiny variations in the area's gravity, which highlights any cavities and can study up to 50 metres (164 feet) underground. Microgravity is used in tandem with seismic refraction, which provides an image profile of rock types. Combined, they can decipher whether you are dealing with dry cracks or wet, soft, porous soil.

As well as using these conventional techniques, NASA uses airborne radar. Known as InSAR, satellites collect images of ground surface layers that show land deformation, which is a known precursor to possible sinkhole formation. NASA predicts that if data is collected continuously and consistently, they will be able to successfully calculate when, where and to what extent sinkholes will occur in a given area.

“Not all sinkholes occur in the wilderness, with holes evermore frequently opening up in urban areas”

ground’s structural integrity. Indeed, the number of human-induced sinkholes has doubled since 1930 as a consequence of both construction and destruction. However, as Dr Vanessa Banks points out, not all rural sinkholes are reported, meaning the notion that more happen in urban areas is slightly flawed due to a lack of rural sinkhole data.

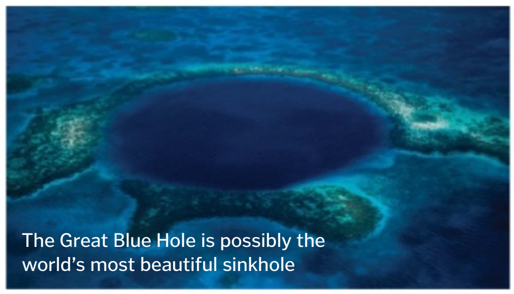
There are a few warning signs to look out for, including slumping and wilting vegetation and cracked walls or foundations. Rain pooling in areas it previously hadn’t can also be a telltale sign. If a sinkhole does occur in your proximity, there are a few essential steps you need to take. Engineering geologist Dr Clive Edmonds told us the best course of action:

“It all depends upon the circumstances. If the stability of a building is threatened by a sinkhole occurring beneath it, then contact your insurer and get an experienced geotechnical engineer to quickly action the infilling of the hole to choke it and stop it from expanding laterally and deepening.“

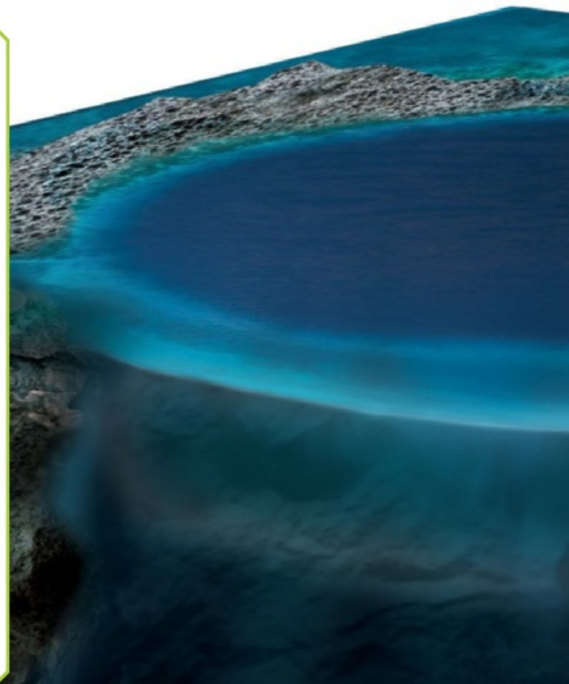
As time goes on, there are new ways to prevent sinkholes from forming. Raft foundation is the use of reinforced concrete slabs to provide an underpinning base that strengthens the ground. Geogrids are made from tough fibreglass with a polymer coating and are an artificial soil structure. A mixture of water, cement and sand creates grout, which is used to combat the development of voids in the soil at specific ‘injection points’. This provides a more stable platform for buildings, while reducing the stress on the ground.

Sinkholes at sea

Lying off the coast of Belize, the Great Blue Hole is the widest ocean sinkhole on the planet. A UNESCO World Heritage Site, it is nestled deep within the Lighthouse Reef Atoll and is a staggering 300 metres (984 feet) in diameter and 125 metres (410 feet) deep. Formed by the falling through of an ancient cave, it used to be on land but rising sea levels thousands of years ago plunged it into the water. Its dry origins are evident in the presence of stalactites, which can only develop on land. Today, the sight is a popular attraction for scuba divers who flock to it from all over the globe.



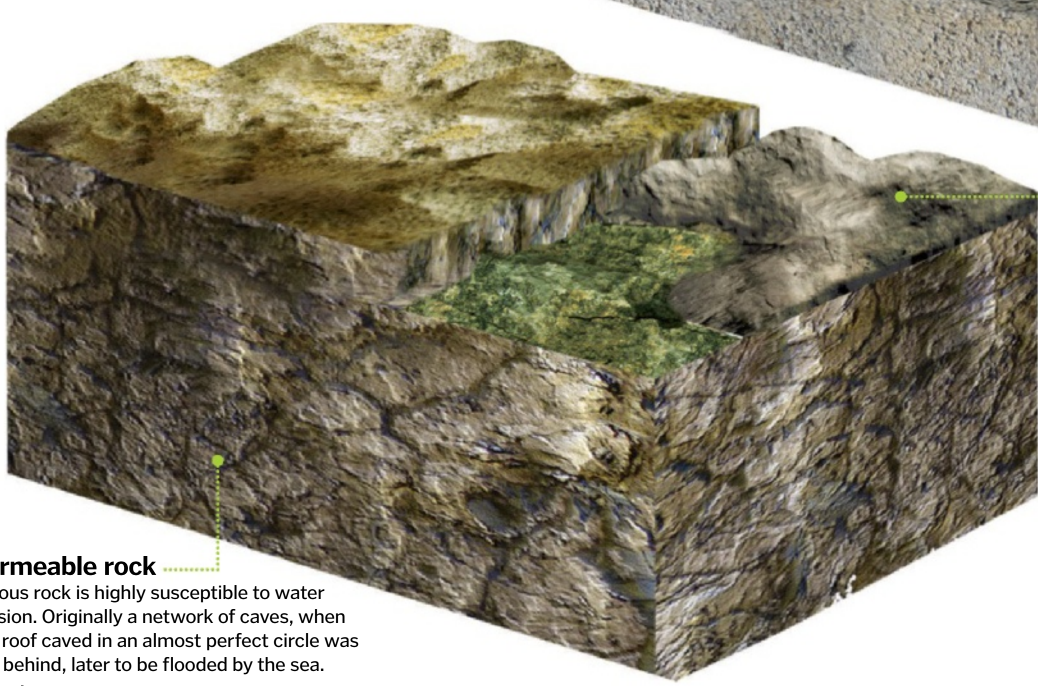
The Great Blue Hole is possibly the world’s most beautiful sinkhole



Flowstone and stalactites
The underground caves still have flowstone and stalactite pillars around its central chamber, revealing its dry land roots.

Algae
As well as coral, algae are frequent visitors to the atoll and the sinkhole is home to a variety of marine life.

Underwater dune
Sand and sediment carried into the hole by the ocean is deposited at the bottom and is shaped into mini dunes.



Bedrock
The Great Blue Hole started life on land. The tough surface rock was eroded over many years in a region of karst terrain.

Permeable rock
Porous rock is highly susceptible to water erosion. Originally a network of caves, when the roof caved in an almost perfect circle was left behind, later to be flooded by the sea.

5 TOP FACTS
FAMOUS SINKHOLES

Ripon, North Yorkshire
1 As recently as February 2014, Ripon in North Yorkshire, Britain, experienced a 7.5-metre (25-foot)-wide hole, where three houses had to be evacuated in a hurry.

Guatemala City
2 In May 2010, a combination of a tropical storm and a volcanic eruption resulted in a huge sinkhole in Guatemala City that swallowed a factory and caused a state of emergency.

Rocksprings, TX
3 In the rural Rocksprings area of Texas, limestone rocks have caused the formation of the 107-metre (350-foot)-deep Devil's Sinkhole, which hosts over 3 million resident bats.

Slovenia
4 Sinkholes have affected man-made infrastructure in Slovenia. Built over areas of karst, small but frequent caverns regularly waylay construction projects.

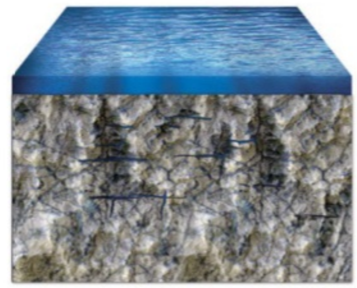
Yucatán Peninsula
5 This area is strewn with limestone sinkholes, or cenotes, that form from collapsed caves and can be up to a stomach-churning 50 metres (164 feet) deep each.

DID YOU KNOW? *The Great Blue Hole is the widest but Dean's Blue Hole is the deepest ocean sinkhole at 202m (663ft)*

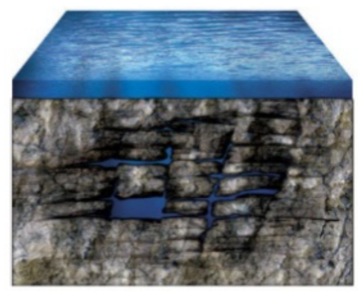
Coral
An ideal habitat for coral, it surrounds the hole and can be seen on the surface at low tide.

Coloration
The vivid colour is a result of blue light refracting off white carbonate sand, while other colours of light in the spectrum are absorbed. The hue varies depending on the depth to the seabed.

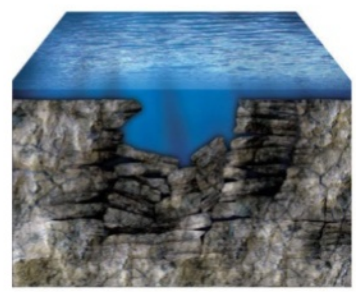
How blue holes are formed



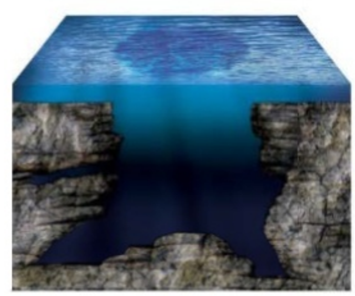
1. Surface erosion
Rain and tidal water gradually eats away an area of hard bedrock, exposing the weaker, soluble carbonate rocks like limestone.



2. Cave network
With no bedrock, the water is now free to corrode the soluble rock. This begins the formation of an underground cavern system.



3. Collapse
The weak limestone is soon dissolved altogether and the cave roof collapses into the crevasse leaving behind a sinkhole.



4. Rise of the ocean
As sea levels rise after an ice age, the area is flooded permanently, creating an ocean sinkhole.

Sinkhole hotspots

One of the most prominent sinkhole areas on Earth is the US state of Florida. This peninsula is dominated by carbonate platforms like limestone that are covered by sand and clay. These soluble materials are battered by erosion and weathering, resulting in a lot of hazardous topography in the Sunshine State. The karst geology was formed after lowering sea levels during the last ice age created new reclaimed land, which had high underground water levels. The underground water reacts with carbon dioxide to form carbonic acid, which erodes the soluble soil and rock. With this topography making water a constant feature, sinkholes are regularly present in the wetlands and Everglades of Florida. Another suffering area is the Dead Sea; the sea is rapidly drying up, partly as a result of heavy irrigation, opening up sinkholes all over the region.

Sinkholes emerge all over Florida, like this one outside the city of Live Oak

ON THE MAP

Major sinkholes around the globe

1 Great Blue Hole, Belize
2 Winter Park, Florida
3 Qattara Depression, Egypt
4 Ripon, North Yorkshire, UK
5 Guatemala City
6 Xiaozhai Tiankeng, China
7 Devil's Sinkhole, Texas
8 Bimmah sinkhole, northern Oman

"Many plants could not grow without a fungus wrapped around and penetrating their roots"

The mysteries of mushrooms

Neither plants nor animals, mushrooms and toadstools play a vital role in the natural world

Imagine an apple tree that grows entirely underground. All we ever see are apples, mysteriously appearing at the surface in autumn. That is essentially how fungi live. The main part of their structure is a vast network of fine threads, called a mycelium, which spreads through the soil or other substrate. Often, all we see of them are their fruiting bodies which appear above ground, usually in late summer or autumn. We call these mushrooms if they are edible or toadstools if they are inedible, although there is no scientific distinction between the two.

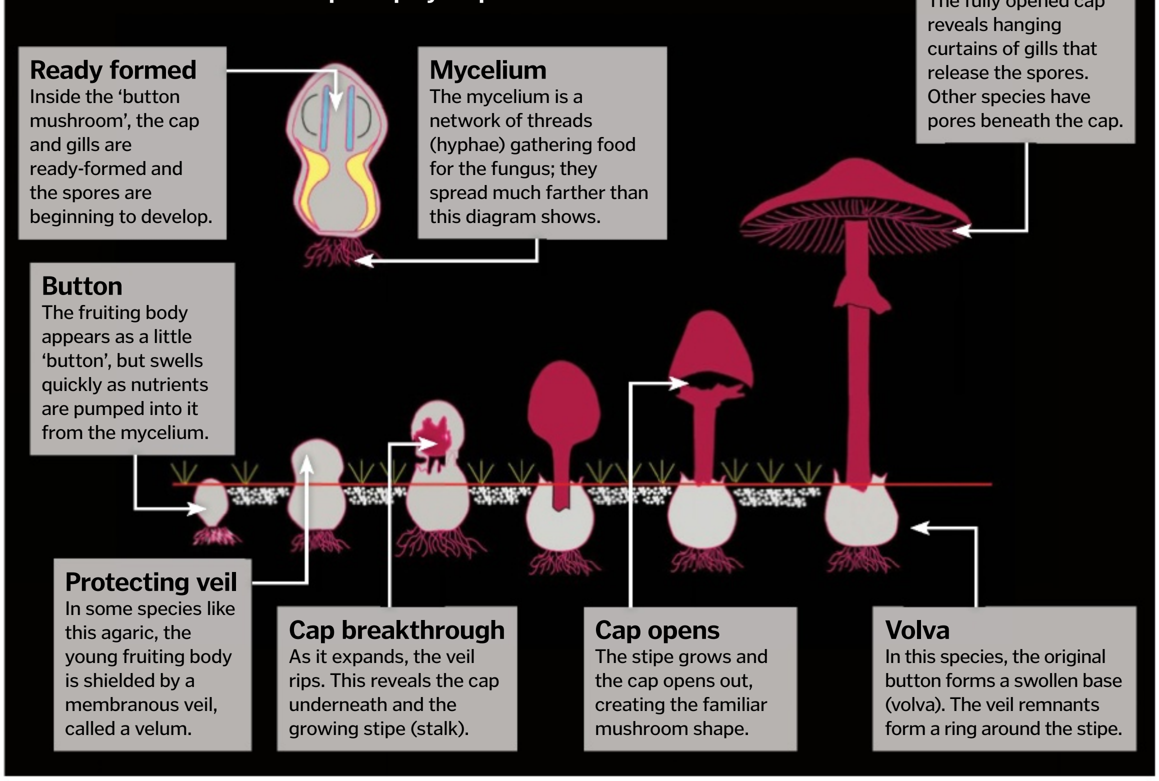
The fungal mycelium grows through its food, which might be soil, old leaf litter, dead trees, wood of living trees or even dead animals. The threads (called hyphae) can reach out huge distances to find food. Although some fungi attack and kill living plants (especially trees) and animals, many are beneficial, by decomposing dead material and releasing its goodness back into the soil.

Many trees, orchids and other plants could not grow without a fungus wrapped around and penetrating their roots. This intimate partnership, called a mycorrhiza, takes nutrients from the soil to feed the host plant and, in return, the fungus is protected.

Fungi are truly ancient. The remains of plants fossilised some 400 million years ago in rocks at Rhynie in Scotland had fungal mycelia in their roots. Fungi were once classed as plants, but their lifestyle is so unique that scientists now place them in their own distinct kingdom.

Anatomy of a toadstool

See how a mushroom develops step by step



5 fantastic fungi

1 Fly agaric

This poisonous toadstool with a white-spotted red cap is familiar from fairy tales. It grows in most parts of the world, usually near birch trees because its mycelium forms a mycorrhiza with birch roots.

2 Stinkhorn fungus

When its spores are ripe, the veil splits off the cap, revealing a foul-smelling, black mass of spores beneath. The smell attracts flies that carry off the sticky spores, helping to spread the species.

3 Puffball

The caps of these fungi have thin, papery walls, perforated by pores. They contain a mass of powdery spores. Raindrops hitting the balloon-like caps cause puffs of spores to be blown out and dispersed in the wind.

4 Bracket fungus

These tough, woody fungi are shaped like a rounded shelf or a horse's hoof growing from the side of a tree. Their hyphae grow through the wood, causing it to rot; sometimes this will eventually kill the tree.

5 Dry rot

Spotting the bracket-like fruit body of this fungus in a poorly ventilated building is bad news. By then, its white mycelium will have spread widely through structural timbers, causing serious rot and requiring the building to be gutted.

RECORD BREAKERS
A LONG STREET

720km

BIGGEST VON KÁRMÁN VORTEX STREET

The longest Von Kármán vortex streets are usually to be found streaming from the Hallasan Volcano on South Korea's Jeju Island. The longest one measured to date ran for an incredible 720km (450mi) before it broke up.

DID YOU KNOW? Bees have been found to make use of vortices by taking advantage of energy created by the swirling eddies

What are Von Kármán vortices?

The science behind these mind-boggling, swirling cloud formations revealed

The area of fluid dynamics is one in which scientists are still getting to grips with, but back in 1911, a Hungarian called Theodore von Kármán worked with a flow tank to demonstrate the effect that a stationary body can have on the flow of a fluid passing over and around it.

As the fluid flow, such as a cloud formation, is disrupted by a cylinder – in nature this is generally an island or group of islands – the fluid is forced to either side of the barrier. The fluid flows around the obstruction, forming a boundary layer close to the object, which hugs it closely. As the flow continues, the boundary layer becomes a shear layer, which continues to move away from the barrier. If there is any kind of pressure imbalance coming from either side of the barrier, the side with greater pressure forces the fluid flow upward, separating it from the main flow and causing a swirling eddy. Having broken off one stream, the cloud then folds back on itself, causing the side with more pressure to be cut off and swirl away in the opposite rotational direction, creating a vortex.

As the flow continues, the alternation of pressure imbalances continues, generating what is known as a 'street' of repeated vortices swirling in different directions (see image), pushed along by the fluid flow.

However, not all fluids that meet a barrier result in a Von Kármán vortex street. The pressure imbalance is measured by using Reynolds numbers, which represent the ratio of moving forces to stationary forces in a fluid flow. The higher the Reynolds number, the more likely a fluid flow will be turbulent rather than laminar (ie a smooth flow).

This phenomenon is most commonly seen in clouds as they are pushed along by the air current and disturbed by high-above-sea-level islands and mountains, but they can also be observed in the ocean and on ice.

The man behind the mystery

Theodore von Kármán was born in Budapest, Hungary, on 11 May 1881. His father, a philosophy and education professor, made him practise subjects such as geography and history. However, Von Kármán's natural maths ability shone through and he won the prestigious Eotvos Prize, which was awarded to the country's best maths and science student.

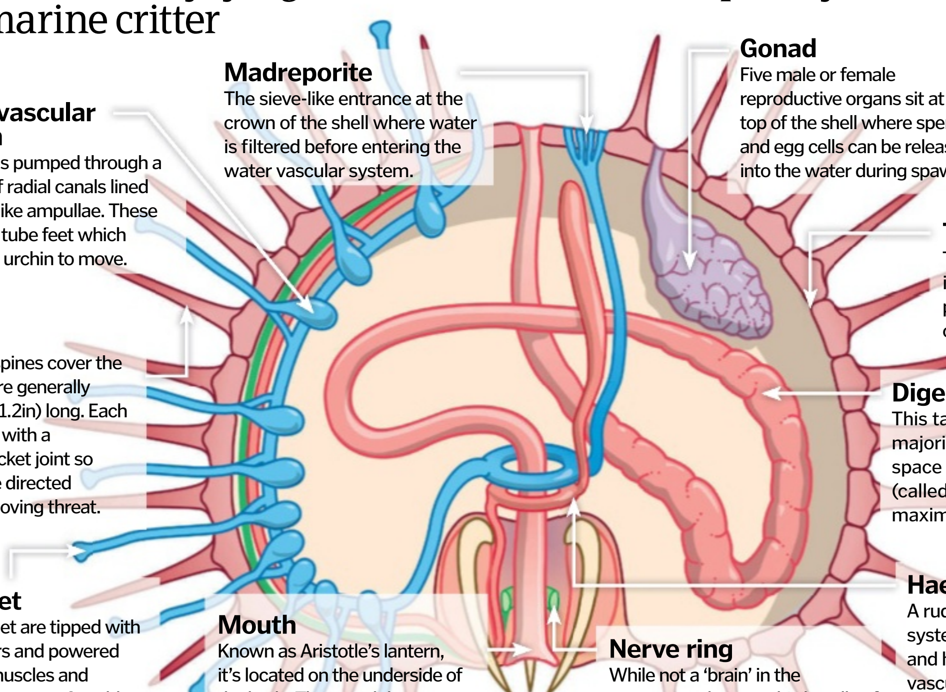
He made his famous breakthrough while working as a privatdozent (university lecturer) in Göttingen in Germany.

Von Kármán vortices being created by the island of Madeira and the Canary Islands in the Atlantic

"Leafcutter ants are capable of carrying leaves up to 50 times their own weight"

Sea urchin biology

The anatomy lying beneath the shell of this prickly marine critter



Water vascular system
Seawater is pumped through a network of radial canals lined with bulb-like ampullae. These power the tube feet which enable the urchin to move.

Madreporite
The sieve-like entrance at the crown of the shell where water is filtered before entering the water vascular system.

Gonad
Five male or female reproductive organs sit at the top of the shell where sperm and egg cells can be released into the water during spawning.

Test
The exoskeleton, known as a test, is comprised of symmetrical plates made largely of calcium carbonate from the seawater.

Spine
Defensive spines cover the body and are generally 1-3cm (0.4-1.2in) long. Each is attached with a ball-and-socket joint so they can be directed toward a moving threat.

Digestive tract
This takes up the majority of the open space inside the shell (called the coelom), to maximise nutrient intake.

Haemal system
A rudimentary circulatory system contains the blood and helps the water vascular system to deliver oxygen around the body.

Tube feet
The tube feet are tipped with mini suckers and powered by paired muscles and hydraulic pressure. Capable of gas exchange, they also support the gills by taking in oxygen and releasing CO_2.

Mouth
Known as Aristotle's lantern, it's located on the underside of the body. The mouth boasts five calcite teeth, each 2cm (0.8in) long and strong enough to chew through rock!

Nerve ring
While not a 'brain' in the conventional sense, this bundle of nerve fibres near the mouth helps to co-ordinate movements and interpret sensory information.

Due to their prickly appearance, sea urchins are sometimes called sea hedgehogs

The statistics...

Purple sea urchin

Binomial: Strongylocentrotus purpuratus

Diet: Omnivore (eg kelp, sponges, barnacles)

Diameter: 5-10cm (2-4in)

Spine length: 2cm (0.8in)

Life span in wild: 20+ years

Range: West coast of North America

Why leafcutter ants cut leaves

What makes these little insects the ultimate sustainable farmers?

Leafcutter ants are a perfect endorsement for teamwork. Living in complex communities with up to 8 million neighbours, individuals dedicate their lives to a single task, each doing their small part to support the colony.

Workers use their powerful jaws to shear off pieces of leaf all the way from the forest floor to the canopy. They are capable of carrying leaves up to 50 times their own weight – that's the equivalent of us walking with a family car over our heads – and they're able to transport even larger fragments by working in groups.

But this foliage isn't their food. It's used as fertiliser for fungi that the insects tend in vast subterranean gardens. It's this fungi which nourishes the colony. As well as ensuring the longevity of the nest, the ants' farming activities – both pruning vegetation above ground and releasing nutrients into the soil below ground – make a major contribution to the survival of their forest home.

Leafcutter ants form some of the most complex animal societies on Earth

Jobs in a leafcutter ant colony

Gardener
These workers rarely leave the nest, spending their lives chewing up the harvested leaves and tending the fungi farm that provides food for the colony.

Soldier
Much bigger than the other workers, soldiers defend the hive from predators and rival ants. Their powerful mandibles can even cut through leather!

Forager
Constantly on the go, they harvest foliage from the forest and carry it to the nest. Their mandibles can vibrate 1,000 times a second to saw through leaves.

Cleaner
A tenth the size of the foragers, they are responsible for cleaning any eggs or parasites off leaves and workers to avoid contaminating the nest.

Queen
The one to establish a colony and produce subsequent generations, the queen is the hive's biggest ant. She can live for over 10 years and lay 30,000 eggs in a day.


"what an honour to be part of Gerald Durrell's vision and study here at the Academy"

"Durrell has changed my life as a biologist"



durrell
Staff

"The taiga experiences long, cold and dry winters with annual temperatures hovering around freezing"

Life in the boreal forest

Covering nearly 20 per cent of our planet's land, how have plants and animals adapted to the cold climate of the taiga?

Boreal forest, also called taiga, covers about 17 per cent of the global land surface, encircling much of the far-Northern Hemisphere. In fact, it's Earth's biggest terrestrial 'biome' – defined as a region sharing similar climate, plants and wildlife.

The taiga experiences long, cold and dry winters with average annual temperatures hovering around freezing, from minus-five to plus-five degrees Celsius (23-41 degrees Fahrenheit). The soil is generally thin, poor in nutrients and acidic, and the majority of water arrives in the form of snow.

The cold climate means the most common plants are coniferous trees, which are tough enough to cope with the harsh conditions. Evergreen trees are green year-round – they keep their leaves during winter to save energy re-growing them in spring. They have waxy needles to reduce water loss when they can't draw water from the frozen ground. Needles are also dark coloured to absorb as much sunlight as possible, while their conical shape helps to shed snow to avoid branches snapping.

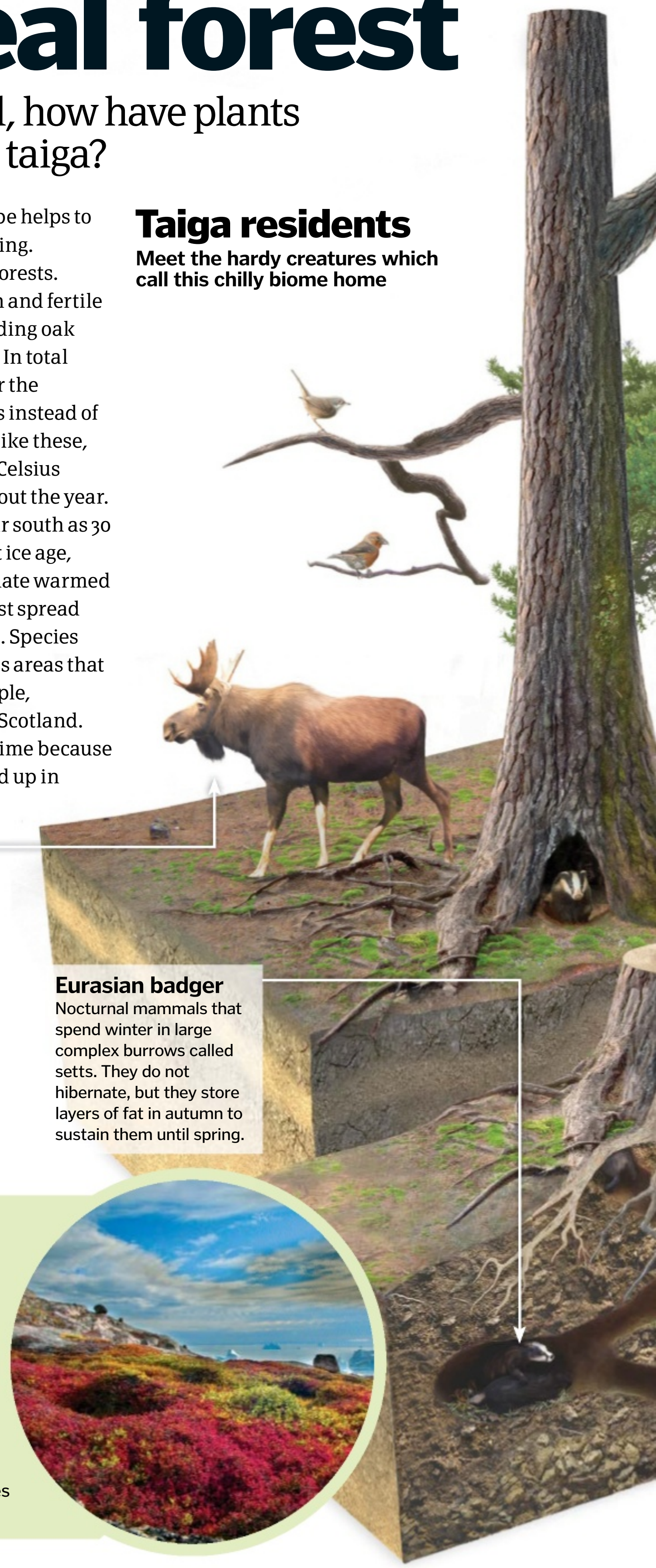
South of the taiga are temperate forests. These have a longer growing season and fertile soil. Their broad-leafed trees, including oak and elm, lose their leaves annually. In total contrast, tropical forests thrive near the equator, with dry and rainy seasons instead of winter and summer. In rainforests like these, temperatures stay at 20-25 degrees Celsius (68-77 degrees Fahrenheit) throughout the year.

Boreal forest species existed as far south as 30 degrees north at the peak of the last ice age, around 21,500 years ago. As the climate warmed and the ice receded, the boreal forest spread through Europe and North America. Species migrated between continents across areas that are covered by sea today – for example, European trees spread to northern Scotland. Sea levels were much lower at this time because a lot of the planet's water was locked up in gigantic ice sheets.


Boreal forest is dominated by evergreen trees like these pines in Québec, Canada

Taiga residents

Meet the hardy creatures which call this chilly biome home



Moose
Earth's largest deer have long legs and hooves to help them navigate deep snow. Males use antlers that can span over 1.5m (5ft) to fight for females during breeding season.

Eurasian badger
Nocturnal mammals that spend winter in large complex burrows called setts. They do not hibernate, but they store layers of fat in autumn to sustain them until spring.

Taiga vs tundra

Tundra (pictured right) is the coldest plant and animal community on land, or terrestrial biome, and lies poleward of the taiga. Average temperatures fall below 0 degrees Celsius (32 degrees Fahrenheit) for six to ten months of the year. Rain or snowfall is less than 250 millimetres (ten inches) a year, which is actually less than some deserts.

The severe environmental conditions mean, unlike boreal forest, tundra has almost no trees. Indeed, the word tundra comes from the Finnish word 'tunturia' meaning 'treeless plain'.

Deep tree roots cannot penetrate the permanently frozen sub-soil called permafrost. When water saturates the upper layers, it gathers in ponds and bogs. Soil is shallow and poor because the cold temperatures slow down nutrient release from dead plants.

The most common vegetation found in tundra includes lichens, mosses, grasses and shrubs. Animals, such as polar bears and Arctic foxes, have adapted to the short summers and long, dark winters by leading a nomadic lifestyle and storing fat reserves to see them through the cold season.

5 TOP FACTS
TAIGA TREES

Scots pine
1 The most widely distributed pine species in the world grows from northern Scotland to eastern Russia. Some of these pines in Scandinavia are more than 700 years old.

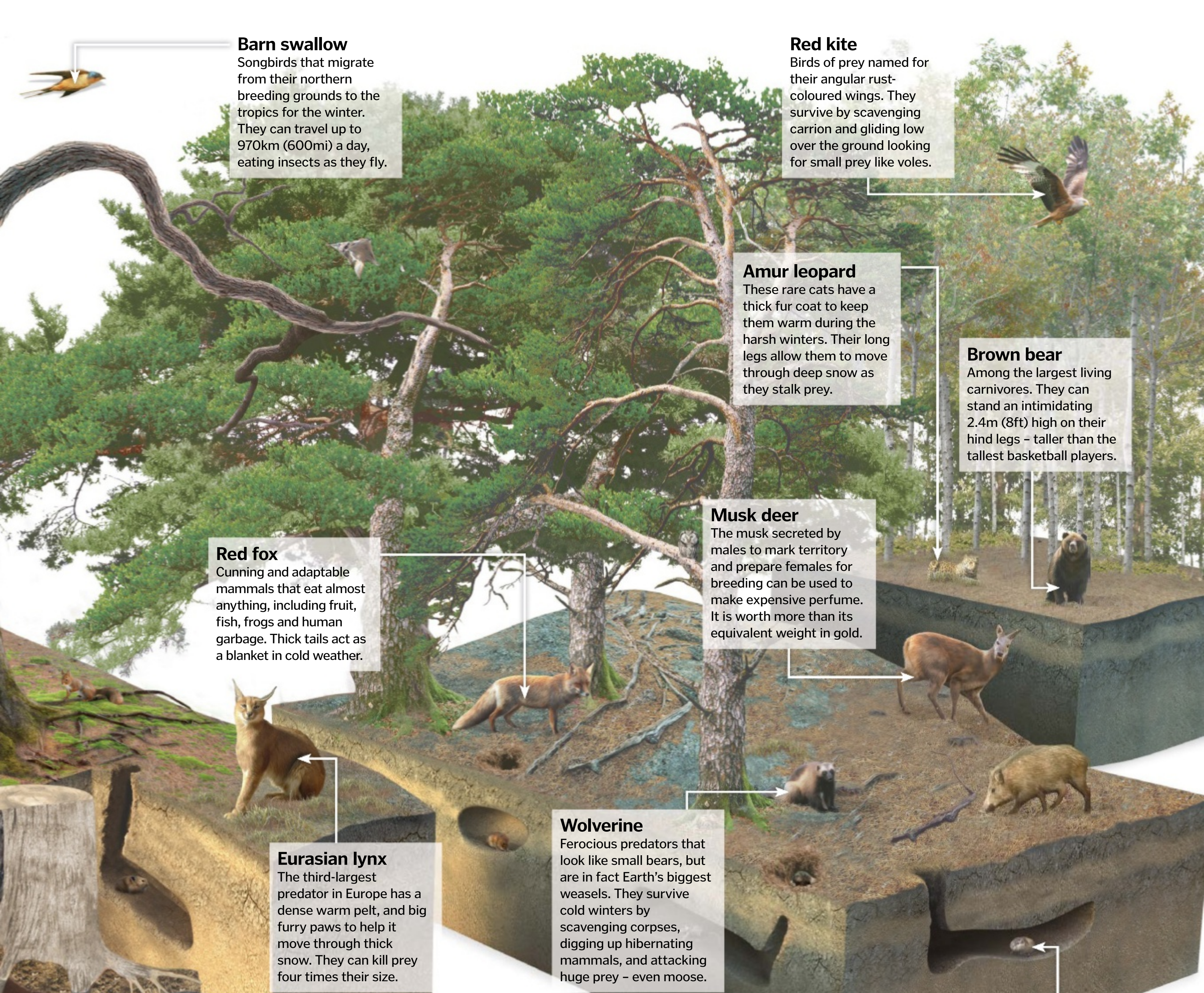
Tamarack
2 Unusually the needles of the tamarack turn gold in the autumn when they lose the green chlorophyll that absorbs the Sun's energy. Most conifers are evergreen.

Black spruce
3 Picea mariana survives boggy conditions with its rough bark and layers of drooping branches. They hoard nutrients in their needles, which can live for 30 years.

Jack pine
4 The most widespread pine in Canada grows in sandy and shallow soil – even on permafrost. Forest fires open the cones, allowing these trees to invade burned land.

Gmelin larch
5 Larix gmelinii thrives in the Russian Verkhoyansk Mountains, where temperatures have plunged to -70°C (-94°F). They survive off moisture from melted permafrost.

DID YOU KNOW? *Taiga is a Russian term for 'little sticks' and describes the small coniferous trees growing in these regions*



Barn swallow
Songbirds that migrate from their northern breeding grounds to the tropics for the winter. They can travel up to 970km (600mi) a day, eating insects as they fly.

Red kite
Birds of prey named for their angular rust-coloured wings. They survive by scavenging carrion and gliding low over the ground looking for small prey like voles.

Amur leopard
These rare cats have a thick fur coat to keep them warm during the harsh winters. Their long legs allow them to move through deep snow as they stalk prey.

Brown bear
Among the largest living carnivores. They can stand an intimidating 2.4m (8ft) high on their hind legs – taller than the tallest basketball players.

Red fox
Cunning and adaptable mammals that eat almost anything, including fruit, fish, frogs and human garbage. Thick tails act as a blanket in cold weather.

Musk deer
The musk secreted by males to mark territory and prepare females for breeding can be used to make expensive perfume. It is worth more than its equivalent weight in gold.

Eurasian lynx
The third-largest predator in Europe has a dense warm pelt, and big furry paws to help it move through thick snow. They can kill prey four times their size.

Wolverine
Ferocious predators that look like small bears, but are in fact Earth's biggest weasels. They survive cold winters by scavenging corpses, digging up hibernating mammals, and attacking huge prey – even moose.

Taiga vole
These rodents keep warm in winter by nesting with five or ten others. Burrow temperatures can stay above freezing while temperatures outside plunge to -23°C (-9°F).

ON THE MAP

Taiga worldwide
1 Scottish Highlands
2 Northern Mongolia
3 Scandinavia
4 Alaska
5 Siberia
6 Canada

A furnace in action – temperatures inside the bowl can reach a fiery 1,650°C (3,000°F)

The tapped out molten steel cools in a ladle, but it's a race against time to use it before it cools too much

The molten steel is made into billets, which are huge rods of steel. They go from glowing red hot to grey in a matter of minutes

THE STATS CELSA STEEL MILL

DAILY SCREENING	1,000 tons	MAXIMUM TEMP	1,650°C	YEARLY OUTPUT	1mn tons
FURNACE VOLTAGE	275v	ELECTRODE COST	£4,000	SLAG PRODUCTION	18,000kg

DID YOU KNOW? *Up until February 2014, China produced more crude steel than the rest of the world combined!*

Making steel

A behind-the-scenes visit to one of the biggest steelworks in Britain reveals how this essential metal is made

Steel is everywhere. Found in bridges, trains, computers and even your cutlery drawer, this alloy is one of the most widely used materials in the world. It is full of properties that make it the go-to choice for the construction of some of the world's most incredible structures, while being adaptable enough to be used for car doors and teaspoons, but how is this amazing construction product constructed itself? To answer this we went to the CELSA Steelworks in Cardiff, Wales, to get to grips with the process of creating steel.

Essentially, there are two main methods of making steel today. One is called basic oxygen steelmaking (BOS), which is how 60 per cent of the world's steel is currently produced. To begin this involves extracting iron ore from rocks in the ground. Next comes a process called smelting. Steelworkers fill a blast furnace with the iron ore, charcoal and limestone, pump vast amounts of air into the bottom – fuelling the fire that was created when an electrical charge was put through the system; this melts the iron down, allowing workers to 'tap' it out of the furnace. Pumping oxygen through the liquid iron oxidises the carbon content and, when it reduces to a certain level, steel is born.

The second process is called electric arc furnace (EAF), which instead of raw materials uses scrap steel to create new metal. It is this latter process which is employed at Cardiff's CELSA steelworks, all overseen by Ron Davidge, who has worked for several years in the steelmaking industry – first in the melt shop and then the control room.

HIW writer Jamie gets shown around the control room where everything at the plant is carefully monitored

"The EAF process starts in the scrapyard," Davidge tells us. "We put the scrap metal into the screening process and that separates the good steel from the rubbish. It's then loaded into the baskets and brought into the melt shop. We have different metal ratios based on the grade of steel we're making. The best steel has a copper content of around 20 per cent. Much more and the steel is weakened, as copper wire has a habit of breaking up under pressure."

The melt shop is the vast open building in which the really exciting part of steelmaking occurs – home to the furnace fire.

With a wrenching and a scraping, the lid is lifted off the furnace and the huge basket full of pieces of scrap metal is tipped into the furnace. Lifted up with the lid are three immense graphite electrodes, which are glowing red-hot.

"We have to keep the furnace at an incredibly hot temperature", explains Davidge, "because if we let it cool down it takes a huge amount of energy and time to reheat and we don't want to waste either of those. After we tip in the metal, the electrodes get lowered and we put an electrical charge through them that is conducted by the scrap. The electrodes have an angled base to increase their surface area."

When it is time for the second bucket of scrap to be lowered into the furnace, which we're told is currently running at around 1,650 degrees Celsius (3,000 degrees Fahrenheit), the lid is

> "Once the majority of the steel has been melted down, a burst of oxygen is sent through"

raised and an incredible ball of flame billows out of the container. The scrap is released into the pit where it is rapidly melted down into the liquid steel bath.

"The walls of the furnace are lined with silica brick, which has a very high melting rate. Even so, the shelf life of even good-quality brick only lasts about three weeks before it needs to be changed. We have to make sure we protect our furnace because they're expensive", says Davidge. "The furnace is also lined with manganese and slag from previous meltings to provide some extra protection."

It is at this point in the process that the BOS and EAF steelmaking methods converge and follow the same path (see diagram, right).

Once the majority of the steel has been melted down, a burst of oxygen is sent through the steel oxidising the contents until most of the impurities are removed and the perfect level of carbon content is reached.

Slag is the thick substance created from all the waste products in the process. In order to remove this, the furnace is tipped back and forth a few times, allowing the waste to be pushed out of the slag door. This process will often lose a bit of liquid steel but it is an acceptable sacrifice at this stage. After as much slag as possible is removed from the furnace, the tapping process can begin.

There are two pipes below the furnace, one of which allows a stream of 145 tons of molten steel to run down it into a bath, while the other contains metals and alloys, such as silicon and

Steel step-by-step

Two routes to making steel explained

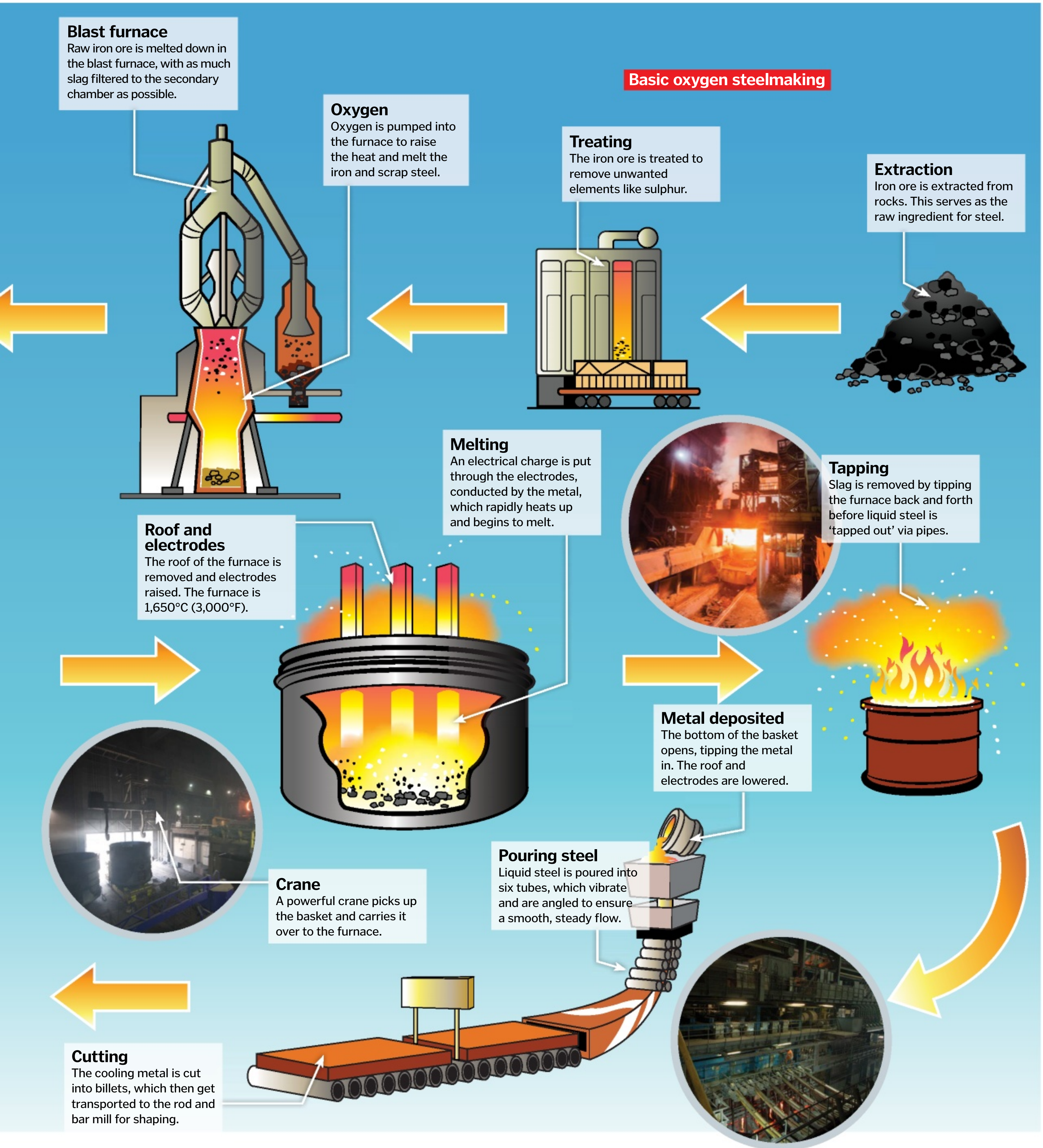

The temperature on the melt shop floor becomes almost unbearably hot as the furnace roars into action

6,000M³

BIGGEST FURNACE ON EARTH

The largest furnace in the world is Furnace 1 at the Gwangyang Steelworks in South Korea. It has a giant capacity of 6,000 cubic metres (212,000 cubic feet).

DID YOU KNOW? *There are more than 3,500 grades of steel, 75 per cent of which have been developed in the last 20 years*



> "The constant flow pushes the molten metal along the line, where it cools surprisingly rapidly"

manganese, which will be poured into the molten metal mixture to create the right grade of steel for that particular batch.

The bath is analysed and more tweaks are made to the constitution of the steel before it is left to cool slightly, developing a dark, bubbling surface skin, looking a bit like a slightly over-grilled cheese sandwich.

The next stage is to turn that molten steel into steel bars and rods. This is done by craning the container up onto a huge rotor arm, which holds one full bath in waiting and another over a trough. This trough has six exit points, through which the molten metal flows. In order to keep it flowing evenly, the trough vibrates slightly, which keeps the liquid metal constantly moving. The exit points are copper pipes, which drop at a slight angle before levelling out to a horizontal half-pipe, much like a kamikaze water slide.

"As well as the vibrating pipes, the angled drop is designed to keep the stream consistent and smooth," Davidge says. "Too sharp a drop and cracks could appear, too shallow a drop and the metal will be too cool for it to be cut."

The constant flow pushes the molten metal along the line, where it cools surprisingly rapidly. Mechanical cutters are set up, again at a slight angle so it can cut the metal in a straight line as it continues to move in a process called

The tapping of the molten steel is an incredible sight. Extra elements like silicon are added at this stage to create the right grade of steel

How do we make steel stainless?

Steel can be made stainless by the adding of at least 10.5 per cent chromium to the melt. When cooled, the chromium protects the steel from rusting by providing an oxide layer on the surface to protect the steel. As the chromium has very low levels of reactivity, it doesn't rust, keeping your cutlery shining for years.

The origins of stainless steel are fairly complicated. As far back as 1821, scientists noticed that alloys of chromium and iron were resistant to rust, but it wasn't until 1913 that the practice took off. Sheffield's Harry Brearley, looking to create rifle barrels that didn't corrode, discovered that steel-chromium alloys with at least six per cent chromium didn't oxidise. Further studies led him to create a steel product with 12.8 per cent chromium, which is widely considered the first genuine stainless steel.

A brief history of steel…

800 BCE
The Iron Age begins. It follows the Bronze Age and heralds the start of iron as the main metal for making tools and weapons.

206 BCE
During the Han Dynasty, Chinese metalworkers produce an early form of heat-treated steel, as well as high-carbon cast iron.

1692
The first recorded creation of steel in Sheffield. It is called blister steel and is formed by using charcoal to melt wrought iron and increase the carbon content to create steel.

1708
A cast iron foundry is established in Shropshire that uses coke, a substance created by heating coal, to make cast iron – free from impurities caused by charcoal and coal.

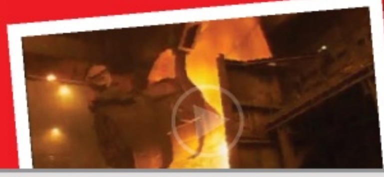
1751
The crucible method of creating steel is developed in Sheffield, in which steel is melted in a crucible to separate slag, which can then be removed.

AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

Watch steelmaking in action at US Steel now!

www.howitworksdaily.com



DID YOU KNOW? *William Kelly, the inventor of modern steelmaking, had to sell his patent to Henry Bessemer due to bankruptcy*

Many workers at the plant have been at the site for decades. One slip-up could ruin an entire day's production

continuous casting. The swiftly cooling billets turn from red to grey in front of our eyes, before being stacked on the back of a huge lorry to be transported to the rod and bar mill where they will be shaped.

The whole process takes around 45 minutes from the moment the first basket of steel is deposited in the furnace to the point at which the container has finished emptying its load of molten steel into the trough.

Any delay would lead to the entire process becoming much less efficient, whether it's the furnace being underused, the molten metal cooling too much and needing reheating or the billet stream grinding to a halt. The plant tends to work 24 hours a day, seven days a week, with maintenance being done in brief periods of downtime or scheduled shutdowns.

We continue outside to take a quick look around the 'slag shed', where all the waste material is deposited. However, this will not get thrown away as the slag can be sold on to companies as a road-building product.

Inside a steelworks is hot, noisy and dusty (they create 50 tons of dust every day) and the pressure to get things right is immense as one slip-up can compromise an entire day's work. Steel is pretty big business and to experience the raw power of that furnace and the dedication of the workers to ensure hundreds of tons of top-quality steel gets produced every day was incredible.

Steel, in its many forms, is a vital material in today's society and its strength, durability and flexibility is only mirrored by the people and the process that creates it.

ON THE MAP

Biggest steel producers by continent

1 China: 62mn tons
2 USA: 6.8mn tons
3 Germany: 3.6mn tons
4 Brazil: 2.6mn tons
5 South Africa: 0.5mn tons
6 Australia: 0.4mn tons

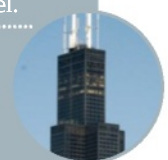
Source: World Steel, Feb 2014

Iconic steel structures

1 Sydney Harbour Bridge

One of the most iconic structures in the world, the Sydney Harbour Bridge spans 1,149m (3,770ft) with the signature arch stretching 503m (1,650ft). The steelwork weighs 52,800 tons and is made of a special steel blend containing Pearlite, which bumped up the carbon content and in doing so increased the strength to 1.3 times that of normal steel.

2 Willis Tower (formerly Sears Tower)



Completed in 1974, the Sears Tower overtook the Empire State Building as the USA's largest steel building, standing 442m (1,450ft) high. It made use of Khan's Bundled Tube principle, which involves a number of steel pipes secured together to create a rigid superstructure that maximises the steel used for efficiency.

3 RMS Titanic

A 2008 study suggested the steel that went into making this 46,000-ton ship could have aided its downfall. As steelmaking was still in its infancy, the ship's metal was ten times as brittle as modern steel, due to open hearth furnaces allowing sulphur, oxygen and phosphorus to infiltrate the metal.

1784

The puddling furnace is developed by Englishman Henry Cort, which decreases carbon content in iron by stirring.

1856

William Kelly and Henry Bessemer discover blowing oxygen through iron creates an efficient way of making steel and they patent this idea.

1876

Sidney Gilchrist Thomas adds limestone to the mixture to remove phosphorus, which makes steel brittle.

1913

Harry Brearley creates stainless steel by mixing chromium in with the steel mixture to form a corrosive-resistant layer.

2003

A patent was filed by Morris Dilmore and James D Ruhlman for Eglin steel, a very strong steel blend with low to medium carbon content. This is thought to be the strongest steel in the world.

“The mechanism shines a light from its LED source onto the wall of the gastrointestinal tract”

Taking photos in the body

How do we capture images from inside the human digestive system?

An endoscopy is any operation involving the study of the inner workings of the human body. Traditionally, an instrument called an endoscope is used, but more recently tiny cameras inside capsules we can swallow have been taking their place. Specialising in the inspection of the intestines, oesophagus and stomach, it can examine places the endoscope could never reach. In particular, it studies the three major sections of the small intestine: the duodenum, jejunum and ileum.

About the size of a pound coin, the capsule transmits images to outside data recorders. It moves naturally through the digestive tract and is designed to help diagnose the causes of chronic diarrhoea, inflammatory bowel disease, abdominal pain and malabsorption.

To capture images, the mechanism shines a light from its LED source onto the wall of any part of the gastrointestinal tract. These images are then transported by radio waves to a nearby receiver or monitor for analysis.

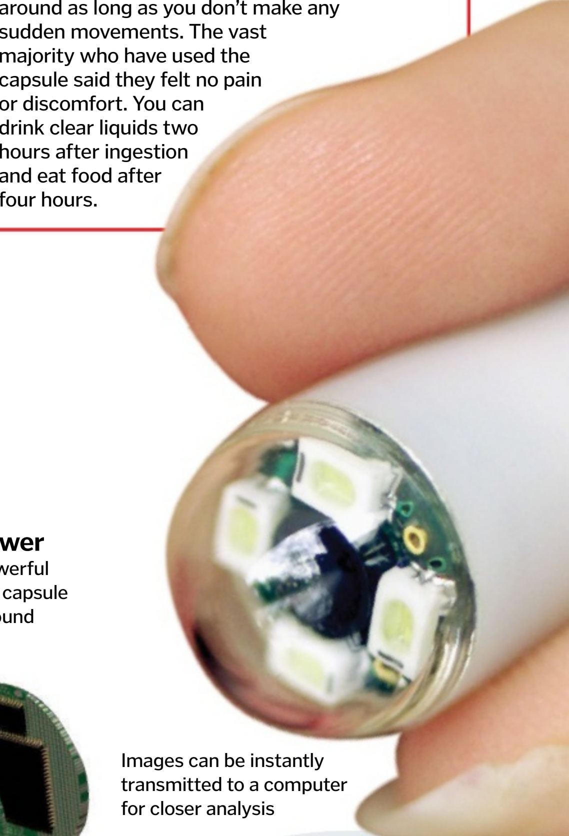
If there’s a downside, it is that currently the camera can’t be stopped to take a closer look at anything, as it’s moved by natural peristalsis.

To date, over 400,000 procedures have been performed worldwide and retention has occurred in only 0.75 per cent of cases, so the chances of it not passing through safely are very slim. In around eight hours the capsule can capture an incredible 50,000 or so images.

It costs about £600 ($1,000) to administer but its ability to explore parts of the digestive system in unprecedented detail – outside invasive surgery – is invaluable.

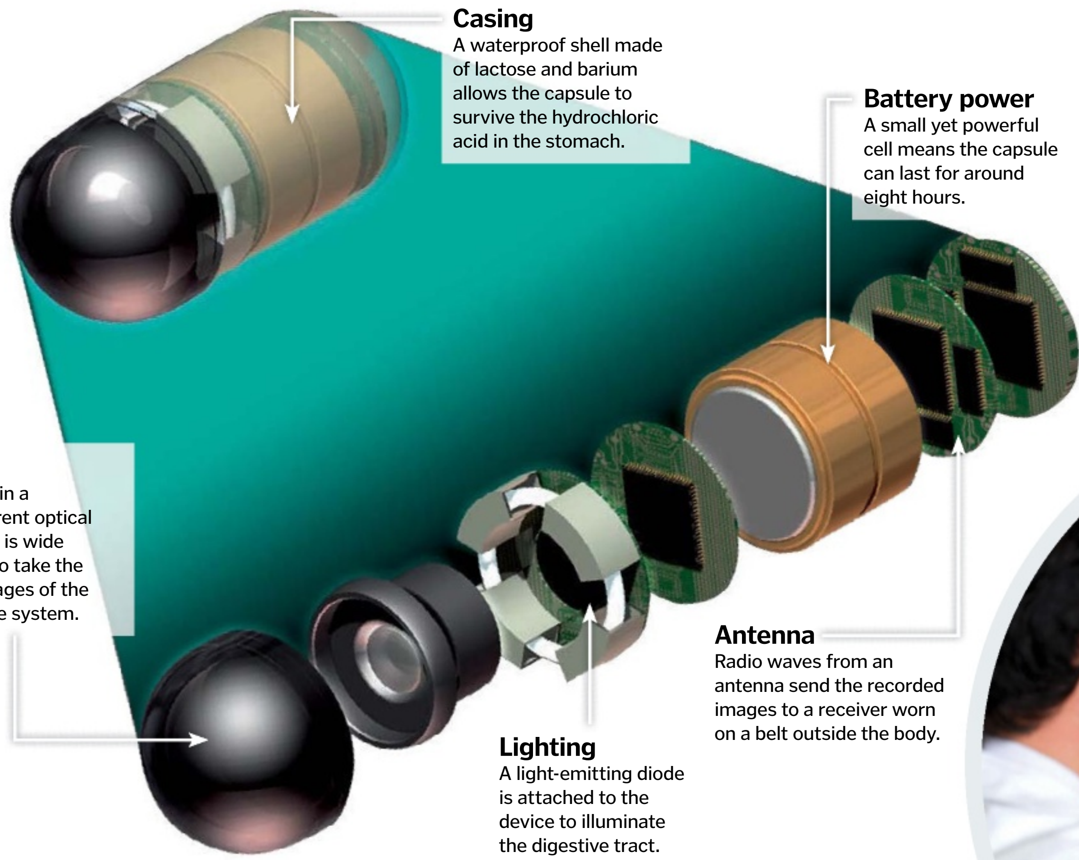
Nil by mouth

Camera capsule endoscopy is a painless and relatively fast process. To allow the procedure to work effectively, the patient must observe a few important measures. Prior to examination, the patient must not eat or drink anything for 12 hours. In some cases, patients may also need to cleanse their bowel before the procedure takes place. After taking the capsule, you can move around as long as you don’t make any sudden movements. The vast majority who have used the capsule said they felt no pain or discomfort. You can drink clear liquids two hours after ingestion and eat food after four hours.


Images can be instantly transmitted to a computer for closer analysis

The camera in a pill

What technology makes up this inner-body explorer?



5 TOP FACTS
POOL OF FABRICS

Cotton
1 The most basic of the costumes, cotton swimsuits aren't the strongest or the most hydrodynamic but they are usually the most comfortable to wear.

Nylon
2 Nylon is the most commonly used material for swimwear due to its light weight and strength, but struggles in the Sun's rays where it can fade, and it also frays over time.

Polyester
3 Polyester is strong and comfortable but its range of merits pales in comparison to nylon so polyester is primarily used in other types of clothing rather than swimsuits.

Spandex
4 Most commonly known as Lycra, spandex boasts excellent elasticity. It is often used with other fabrics as it doesn't hold up well to chlorine and can be itchy.

Polyurethane
5 The pantomime villain of swimsuit materials as it has been banned in competitions. The material enclosed tiny pockets of gas that made swimmers more buoyant.

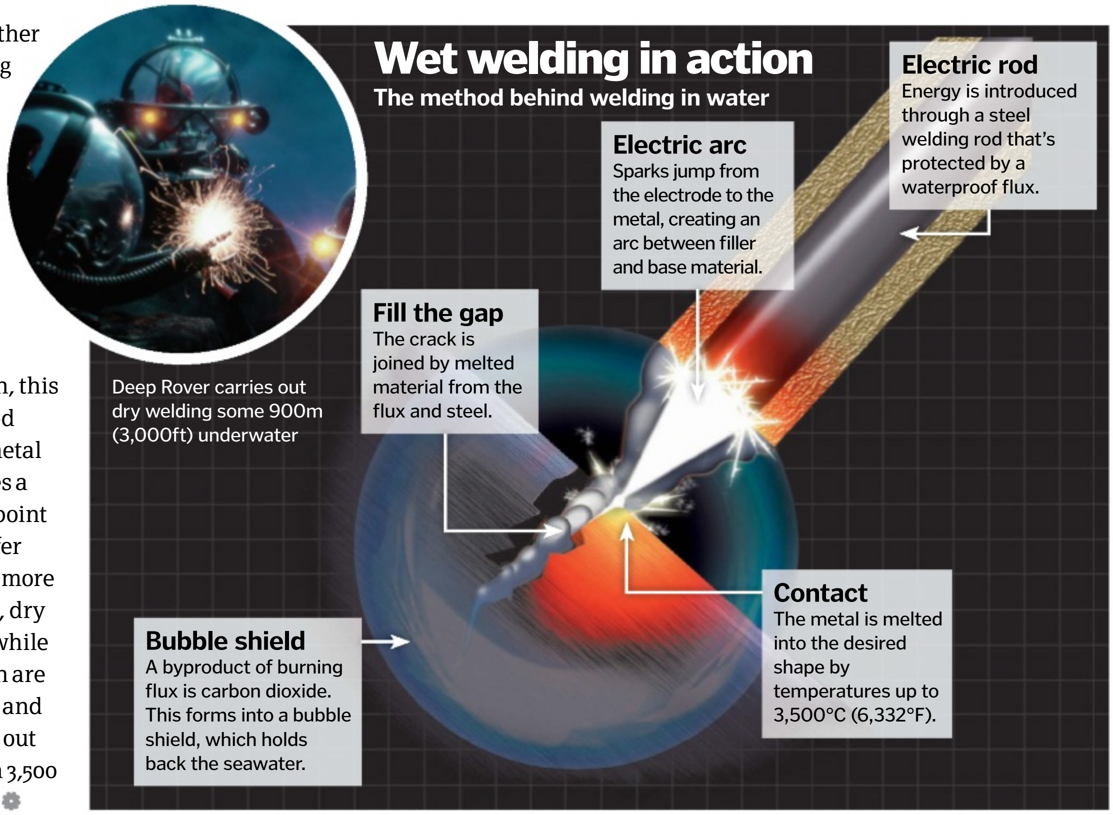
DID YOU KNOW? The world's most expensive bikini is made entirely of diamonds and is worth an estimated £18mn ($30mn)!

How do we weld underwater?

Find out how we patch up holes in vessels and pipes in a watery environment

Joining and fusing materials together has been a key part of engineering for centuries, but what about doing it underwater? High-pressure welding, more formally called hyperbaric fabrication, can now be undertaken in water in two ways.

Dry welding is done in a closed chamber, while wet welding can join metals completely exposed to water. An example of a dry welder is the Deep Rover submersible. Primarily used for exploration, this vehicle can hold up to two people in a sealed sphere and is capable of lifting chunks of metal too. Wet welding, on the other hand, creates a bubble of carbon dioxide around the weld point while the repair is made. Dry welding is safer due to the added protection but tends to be more expensive and time-consuming. Therefore, dry is better for larger, more involved projects while wet is generally used for smaller tasks. Both are used primarily to repair marine structures and deep-sea pipelines and can also be carried out by robots. Welding temperatures can reach 3,500 degrees Celsius (6,330 degrees Fahrenheit).



Deep Rover carries out dry welding some 900m (3,000ft) underwater

Wet welding in action

The method behind welding in water

Electric rod
Energy is introduced through a steel welding rod that's protected by a waterproof flux.

Electric arc
Sparks jump from the electrode to the metal, creating an arc between filler and base material.

Fill the gap
The crack is joined by melted material from the flux and steel.

Contact
The metal is melted into the desired shape by temperatures up to 3,500°C (6,332°F).

Bubble shield
A byproduct of burning flux is carbon dioxide. This forms into a bubble shield, which holds back the seawater.

Why racing swimsuits make us faster

The streamlined fabrics and designs making waves in competitive swimming

Although they may look simple, swimsuits have been engineered to help swimmers glide through the water.

Most important is the hydrodynamic shape. New materials are designed to reduce drag and compress the body into its most streamlined form, helping to reduce lactic acid buildup in the muscles. The fabrics can be made from nylon or spandex and are designed to be lightweight and have a high compression-to-weight ratio. Bonded seams, for instance, create a six per cent reduction in drag compared to sewn seams.

Suits made of hydrophobic (water-resistant) microfilament textiles can reduce drag by eight per cent. They work by effectively pushing the water away from a swimmer's body.

All these measures help swimmers get ever quicker. So quick in fact, that in 2010, polyurethane suits were banned from competitive swimming as they gave an unfair advantage after records tumbled at the 2009 World Swimming Championships.

Comfort is also a priority of course. Special straps help avoid soreness while wide-vision goggles aid sight and reduce drag. Even chemicals are combated with new materials resisting chlorine up to ten times longer than older suits.

Swimsuits have become a hi-tech aid to competitive swimmers in recent years

> "Editing and changing the Steam Machine is actively encouraged so it can cater for your specific needs"

Inside the Steam Machine

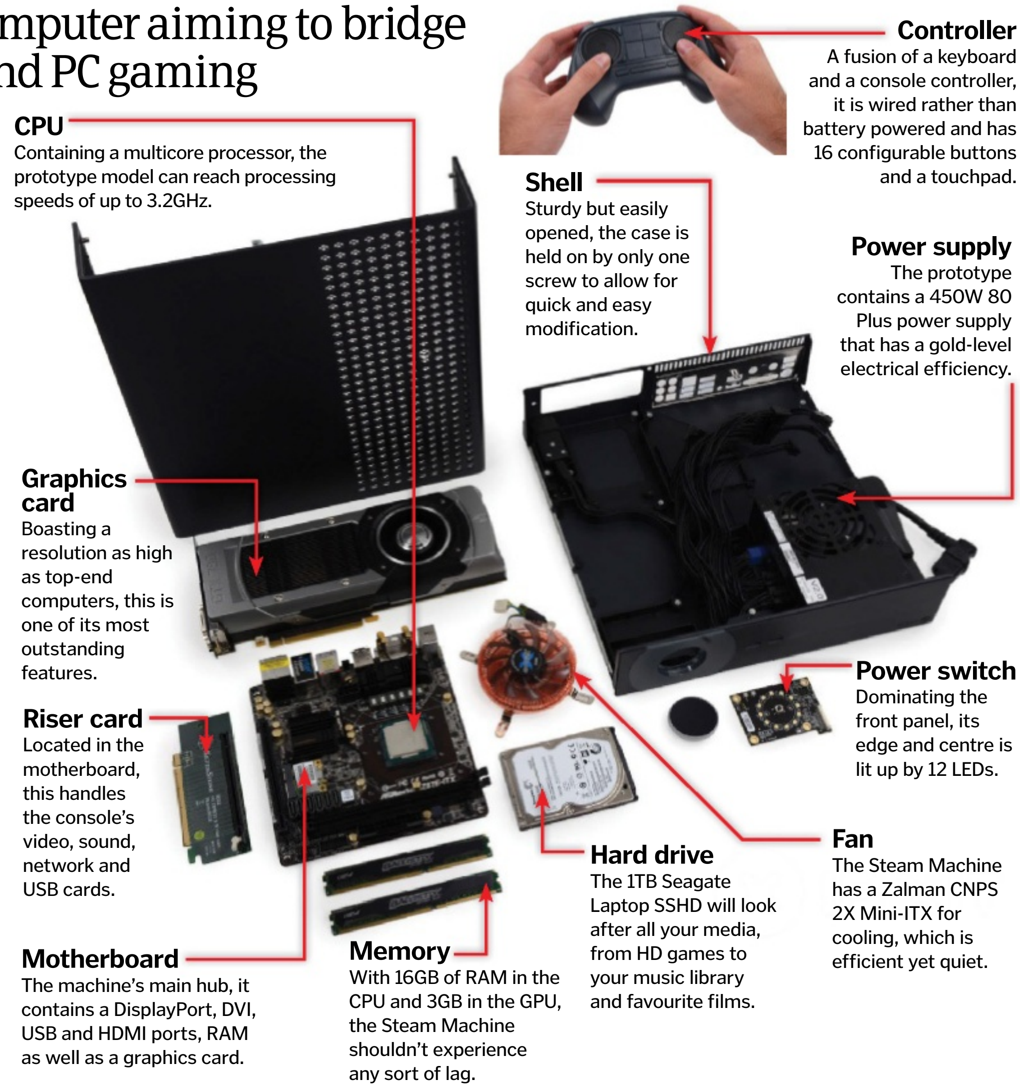
Meet the ambitious new computer aiming to bridge the gap between console and PC gaming

The Valve Corporation is renowned for its Steam system, which distributes and manages PC, OS X and Linux gaming. Its new project, the Steam Machine, looks to revolutionise videogaming as we know it.

Designed to be a link between eighth-generation consoles and PC gaming, editing and changing the Steam Machine is actively encouraged so it can cater for your specific needs. With this in mind, unlike the Wii U, Xbox One and PlayStation 4, the console – like a PC – will have interchangeable graphics cards. Hardcore gamers can plump for the full-HD resolution Nvidia GTX Titan while more recreational users could opt for the GTX 660, which has specs equivalent to the current consoles on the market.

A controller will provide a middle ground between a console gamepad and a laptop trackpad with 16 configurable buttons and a touchscreen, aiming to simplify the PC Steam system and appeal to a broad range of gamers.

The only issue is whether games developers will up sticks and move from established formats to an unknown console, but with the stunning hardware on offer, there's no doubt many will be swayed sooner or later. 300 units are currently available to testers and the next wave of Steam Machines is scheduled for release toward the end of 2014, with models varying from as low as £300 ($500) right up to £3,570 ($6,000).



Three Steam rivals

1 Falcon Northwest Tiki

A staggering £3,570 ($6,000) for a full-spec model with all the trimmings of 6TB storage and 16GB RAM. Adorned with glossy artwork and an Intel Core i7, this could prove to be one of the best Steam Machines.

2 Alienware

A subsidiary of computer giant Dell, the Alienware model will be competitively priced and similarly powered to the PS4 and Xbox One. Like all Steam Machines, however, its ultimate success will be dependent on getting the games developers to jump on board the Steam Machine bandwagon.

3 Bolt II

Made by Digital Storm, the Bolt II is a good all-rounder with a GTX 780 Ti graphics card and a 1TB hard drive, and it also looks the part with a sleek design. An upgrade of the original Bolt, the fans you can see are part of an advanced thermal liquid cooling system to keep it cool and quiet.

DID YOU KNOW? *The earliest panic rooms were in medieval castles where secret rooms allowed nobility to hide during attacks*

How panic rooms work

What goes into the ultimate home defence unit?

Panic rooms hit the spotlight in 2002 when Jodie Foster and Kristen Stewart starred in a film where they were trapped in one, but what are these modern-day boltholes and how are they constructed?

A panic room is a safe place for occupants of a property to go whenever they feel threatened. The danger could be in the form of an intruder or a natural threat like an earthquake or hurricane. These rooms are typically windowless for maximum security and the only weak point of these rooms might be the door, but to combat this, panic room doors are constructed from super-thick steel, have reinforced frames and are fitted with high-level security locks. Fingerprint scanners or keycode entry pads provide an extra barrier, and sometimes the door is so well concealed that a trespasser may not even know the room exists.

The room must provide all the essentials for staying alive during a potential long-term situation, so basic plumbing, air filtration and a good stock of medical kit, food and water are all standard. The most expensive panic rooms might also feature monitors hooked up to a CCTV system to keep an eye on intruders' movements as well as a means of communication to contact the outside world.

Thankfully, most panic rooms aren't as tension-filled as 2002's *Panic Room*

A game of hide and seek

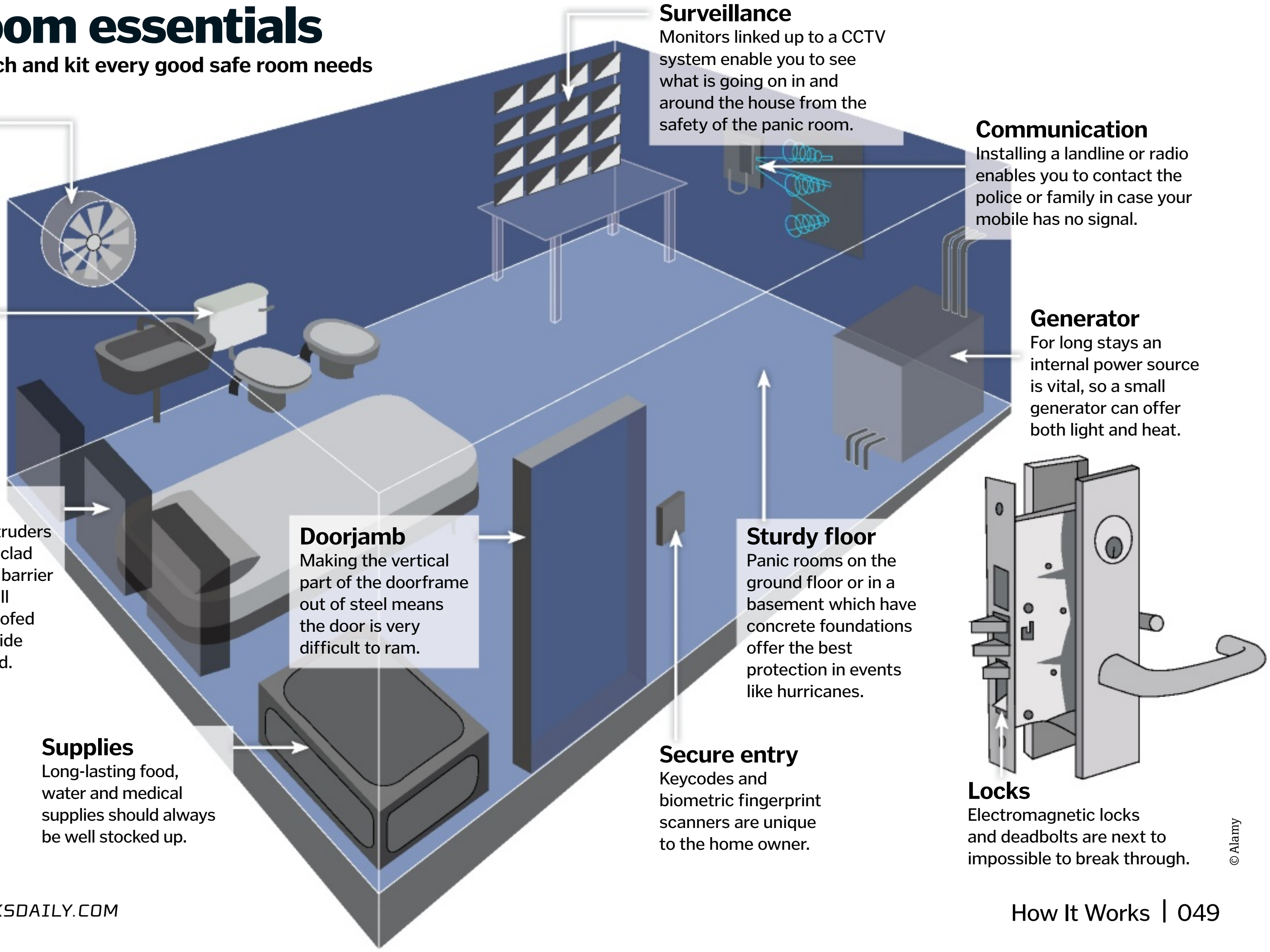
People who are designing custom-built panic rooms to evade intruders are constantly coming up with new and more ingenious ways of keeping these hideaways, well, hidden.

While secret rooms behind bookcases may seem more in line with Enid Blyton fiction than real life, the fact is that a hidden entrance to a panic room could prevent assailants even knowing you're in the building, making it the ultimate defence.

There are examples of panic room doors hidden behind sliding walls, underneath floorboards or through the back of a closet. To ensure a panic room is as well hidden as possible, companies are offering tailor-made services, creating precisely constructed moving walls, which can barely be seen without prior knowledge. Although these are very costly, the peace of mind that comes with increased safety often takes precedence.

Panic room essentials

Explore the key tech and kit every good safe room needs



"Sand filters use pumps to blast the water through and debris is caught by the fine grains"

How to build a mega-aquarium

Dive inside one of the largest aquariums on Earth and discover how we replicate an ocean in a tank

Aquariums, and in particular the awe-inspiring tunnel oceanariums that allow you to walk through marine environments yet stay completely dry, are amazing feats of modern engineering.

First of all, the engineers have to ensure the glass is strong enough to hold back up to 42.8 million litres (11 million gallons) of water. And no, we haven't just plucked that number out of thin air; that's the capacity of the SEA Aquarium in Singapore (see main image).

The SEA's acrylic panel is 36 metres (118 feet) wide, 8.3 metres (27.2 feet) tall and over 70 centimetres (27.6 inches) thick to cope with the immense pressure generated by the huge volume of water. Behind this panel are all manner of marine creatures, from goliath groupers to giant manta rays.

Even after the tanks have been constructed, the water poured in and salinated and the various fish introduced to their respective homes, a lot of upkeep is required. As the tanks are far more contained than the endless oceans, cleaning up waste matter and uneaten food must take place regularly. This is done using one of three common filtration techniques. Mechanical filtration employs filters and pumps to remove waste, fractionation separates the water from particles that have dissolved in it, and finally there is ozone, which kills off harmful bacteria in the water, much like chlorine in swimming pools.

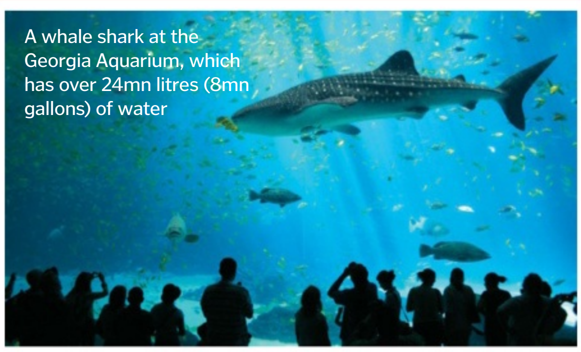
In order to keep the tanks clean for fish and viewers alike, sand filters and skimmers are also incorporated. The sand filters use pumps to blast the water through them and debris is caught by the fine grains, while the protein skimmers pass the water through a valve that injects air into it. This creates lots of tiny bubbles which any debris sticks to.

Clear strength

Aquarium tanks have to meet rigorous safety standards. Often, all that stands between the public and millions of litres of water, sharks and other fish is a single sheet of acrylic. Acrylic has become the standard in aquariums due to its dual qualities of being extremely strong and transparent. The latter quality it, of course, shares with glass, but acrylic's strength really sets it apart.

Acrylic sheets are up to 17 times stronger than glass and have the added advantage of not becoming weakened by prolonged exposure to water. The high molecular weight of cast acrylic sheets makes cutting the panel much easier and the flexible nature of the plastic allows for curved viewing portals without compromising on structural integrity.

Although glass doesn't scratch as easily, acrylic is the way to go for a strong, durable, flexible and transparent material to best show off an aquarium's inhabitants.



A whale shark at the Georgia Aquarium, which has over 24mn litres (8mn gallons) of water

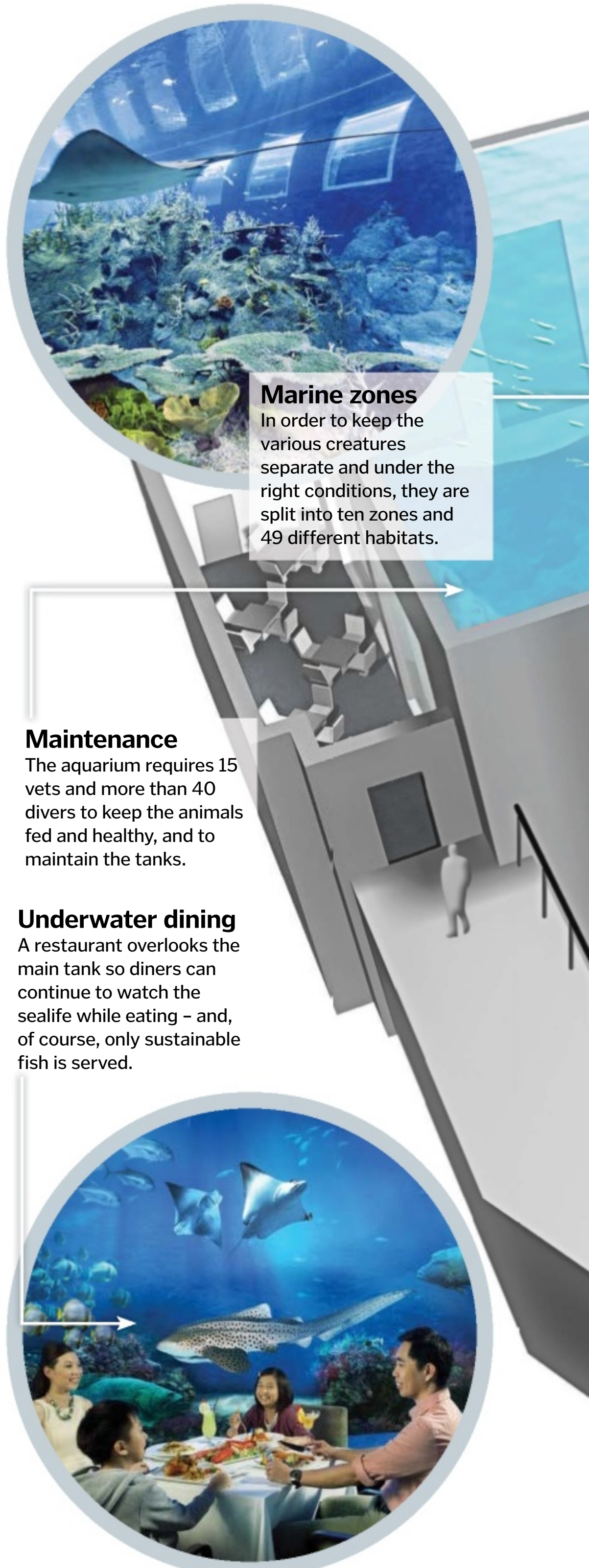
Re-creating marine habitats

Every large aquarium has to deal with the challenge of meeting the needs of the diverse creatures it plays home to. Visitors want to see salt and freshwater fish, plus other creatures, so they have to replicate a variety of environmental conditions. The Ocean Voyager tank in the Georgia Aquarium, USA, poured 680,000 kilograms (1.5 million pounds) of sea salt into its 24-million-litre (6.3-million-gallon) tank. After this initial outlay though, the tank requires very little salt to keep it salinated.

Water temperature is also very important. Depending on the location and inhabitants, temperature varies wildly, so tanks are constantly checked and controlled by thermostats and heaters. For fish that live in deep water, dim lights are used so we can see them without upsetting their natural environment.

Explore the SEA Aquarium

Take a tour of this supersized oceanarium in Singapore



KEY DATES
HISTORY OF AQUARIUMS

50 CE The Romans are credited with the invention of the aquarium, the first a marble tank holding sea barbel.

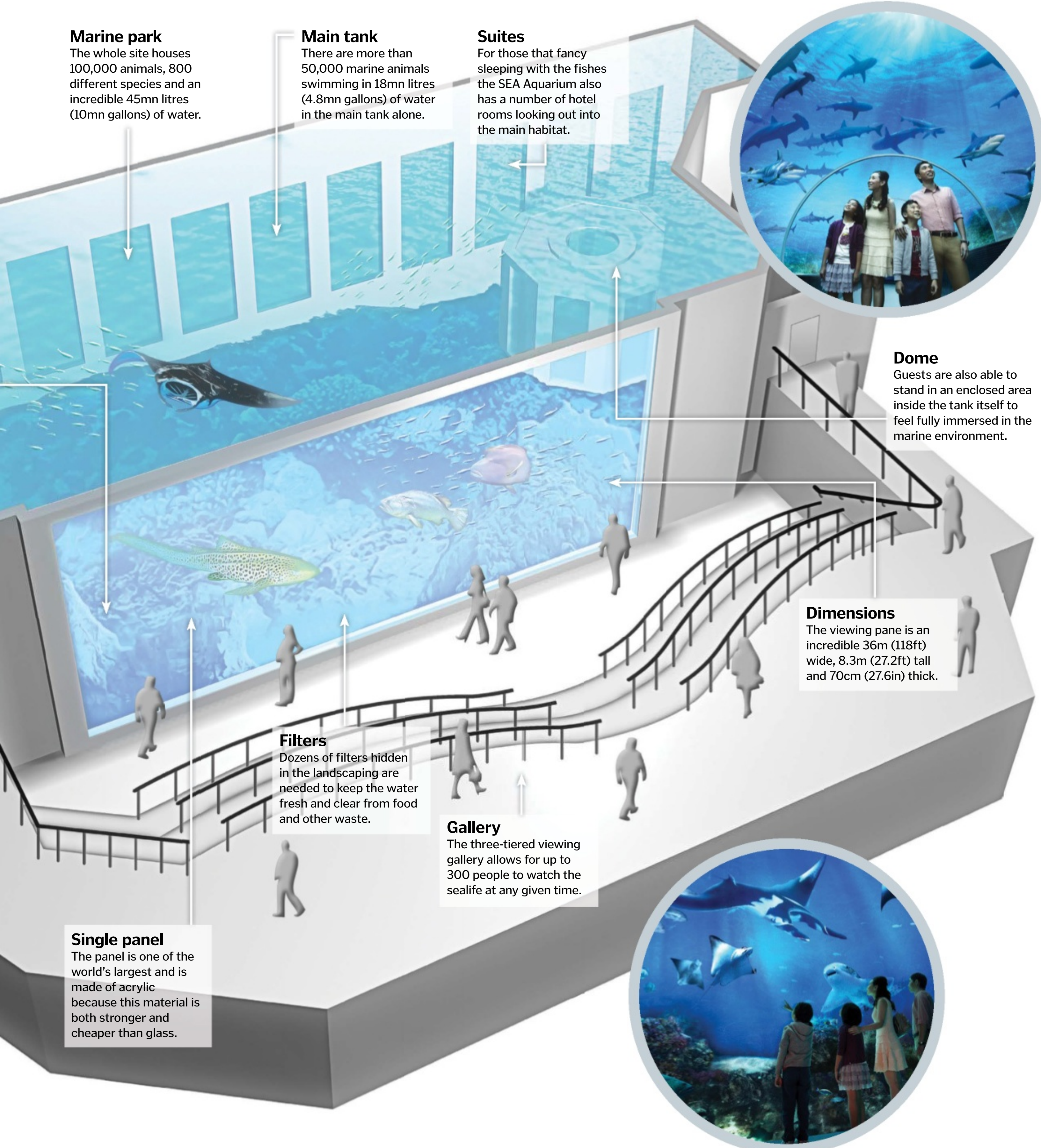
1369 Emperor Hongwu of China orders a porcelain company to begin making tubs to hold goldfish.

1846 Anne Thynne is the first known person to create a balanced aquarium, filling it with coral and seaweed.

1853 The first public aquarium opens in London Zoo, with Philip Henry Gosse (right) coining the word 'aquarium'.

1908 The invention of the mechanical air pump heralds a revolution for aquariums as a home hobby.

DID YOU KNOW? *The biggest acrylic panel is in the Hengqin Ocean Kingdom aquarium in China at 8.3 x 39.6m (27.2 x 129.9ft)*



Marine park
The whole site houses 100,000 animals, 800 different species and an incredible 45mn litres (10mn gallons) of water.

Main tank
There are more than 50,000 marine animals swimming in 18mn litres (4.8mn gallons) of water in the main tank alone.

Suites
For those that fancy sleeping with the fishes the SEA Aquarium also has a number of hotel rooms looking out into the main habitat.

Dome
Guests are also able to stand in an enclosed area inside the tank itself to feel fully immersed in the marine environment.

Dimensions
The viewing pane is an incredible 36m (118ft) wide, 8.3m (27.2ft) tall and 70cm (27.6in) thick.

Filters
Dozens of filters hidden in the landscaping are needed to keep the water fresh and clear from food and other waste.

Gallery
The three-tiered viewing gallery allows for up to 300 people to watch the sealife at any given time.

Single panel
The panel is one of the world's largest and is made of acrylic because this material is both stronger and cheaper than glass.

The secrets of light speed

& the fastest phenomena in space

High-velocity particles can tell us a lot about the way the universe works – but can we ever overcome the ultimate speed limit?

For a few months in early-2012, the scientific world held its breath as researchers raced to establish whether one of the greatest tenets of modern physics was under threat. The panic was triggered by reports from the Gran Sasso National Laboratory, beneath Italy's Apennine Mountains, which appeared to show bursts of neutrinos (tiny, near-massless subatomic particles), fired from a particle accelerator at CERN on the Swiss/French border some 730 kilometres (454 miles) distant, travelling faster than the speed of light.

According to more than a century of established physics, the speed of light in a vacuum, 299,792.458 kilometres (186,282.397 miles) per second – is the ultimate speed limit of the universe. No object with mass can reach this speed for very good reasons outlined in the work of Albert Einstein; as they get close, travelling at so-called 'relativistic' speeds, the strange effects predicted by Einstein's theory of special relativity take effect, including time slowing down, distances contracting and mass increasing (making it ever-more difficult to accelerate). Only massless photons of light and other electromagnetic radiation can reach the speed of light itself.

Sadly for those anticipating a revolution in physics sources, rigorous checking at Gran Sasso eventually identified errors in the timing of the neutrino bursts, confirming they had, in fact, not exceeded the speed of light: for the moment at least, the status quo prevails.

But 'superfast' doesn't always have to threaten the fundamental laws of physics – objects moving far faster than we would expect, even if not at relativistic speeds, can still present us with intriguing puzzles.

Looked at from this perspective, our universe is full of superfast phenomena – from weird particles that get within a trillionth of a per cent of light speed itself, to planets, stars and even man-made space probes moving far, far faster than a speeding bullet.

1. SLOW

Vela 1A
Launched in 1963, this defunct monitoring satellite (Vela 5B pictured) takes 4.5 days to orbit Earth, moving at a speed of 1.8km/s (1.1mi/s).

2. SLOWER

Sedna
One of the most distant objects in the Solar System, this remote world ambles along its orbit at a sluggish average of a mere 1km/s (0.6mi/s).

3. SLOWEST

Halley's Comet
At the outer limits of its 76-year orbit (somewhere beyond Neptune), the famous Halley's Comet crawls along at just 880m/s (2,887ft/s).

DID YOU KNOW? *Central galactic star, S2, is thought to move at blistering speeds of up to 5,000km (3,107mi) per second!*

Special relativity and the ultimate speed limit

Albert Einstein developed his theory of special relativity in order to resolve a crisis in physics during the late-19th century. As methods for measuring the speed of light got more and more accurate, it became clear that it did not behave like other phenomena – its speed was always the same, regardless of the relative motions of source and observer. Physicists tried various tricks to get around the problem, but Einstein was the only person who dared to tackle it head on. He rewrote the laws of physics from the ground up based on two simple principles: a fixed speed of light and the 'principle of special relativity' – that the laws of physics should appear the same for all observers in 'inertial reference frames' (situations and viewpoints not involving acceleration or deceleration).

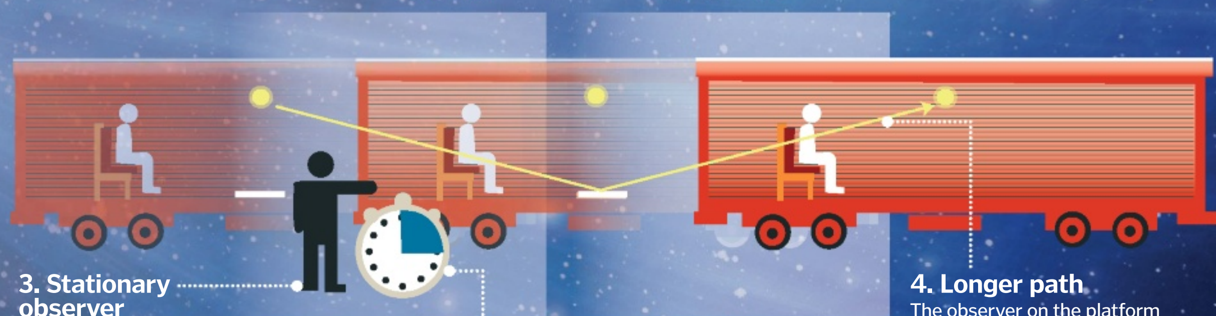
Einstein showed that objects moving at 'relativistic' speeds (superfast speeds comparable to that of light) must experience distortions in their apparent mass, length and even the flow of time (as seen from the point of view of an outside observer). These distortions become infinite when an object attempts to move at the speed of light itself, convincing Einstein that light speed is the ultimate speed limit. Einstein's theory now has more than a century of experimental observations to back it up.

Why is it all relative?

Seen from outside, objects moving close to light speed undergo a contraction in their length and a slowing in the flow of time

1. Measuring time
Light travels at a fixed speed, so a person in a sealed train carriage could use the interval taken for light to bounce from ceiling to floor and back as a measure of time.

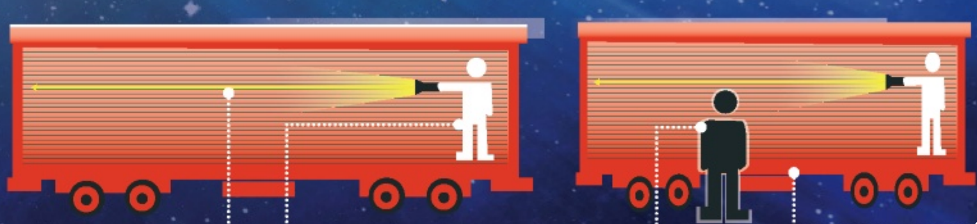
2. Inertial reference frame
Assuming the carriage is not accelerating or decelerating, then according to the man on the train, the light takes the shortest, vertical path up and down.



3. Stationary observer
Now consider an external observer standing on the station platform and watching the train passing at high speed…

4. Longer path
The observer on the platform sees light travel a much longer, diagonal path from ceiling to floor and back. Since light travels at a fixed speed, they measure a longer time interval.

5. Relativity of time
Therefore the stationary observer and the man on the train measure different times for the same event. The faster the train moves, the longer the interval becomes as measured from outside – an effect known as time dilation.



6. Measuring length
The fixed speed of light also means we can use the time it takes to travel between objects as a measure of distance.

7. Inertial reference frame
The man on the train measures the length of his carriage by timing how long a light ray takes to travel along its length.

8. Outside observer
The outside observer sees the end of the carriage moving toward the light ray, so the path the light takes is shorter.

9. Lorentz contraction
The two people disagree on the length of the train carriage; the outside observer sees what is known as a 'Lorentz contraction' that increases with the speed of the train.

> "In blazars, the axis of the jets points more or less straight toward Earth"

Quick-fire blazar jets

Blazars are distant 'active galaxies' with the supermassive black holes in their cores feeding voraciously on matter from their surroundings. Gas and dust spiralling into the black hole forms a superhot disc that from a distance looks like a rapidly changing, starlike point of light, while a powerful magnetic field spits out jets of particles perpendicular to the disc at relativistic speeds. In other types of active galaxy, we see this jet at an angle, but in blazars, the axis of the jets points more or less straight toward Earth. This creates an illusion of faster-than-light motion – material moving along the jet is almost able to keep pace with the radiation it emits, so emissions from a knot of material emitted near the blazar's core arrive at Earth just shortly after those emitted by the same material much farther out, giving the impression that the knot may be moving at many times the speed of light, but this is an illusion.

Hunting for blazars

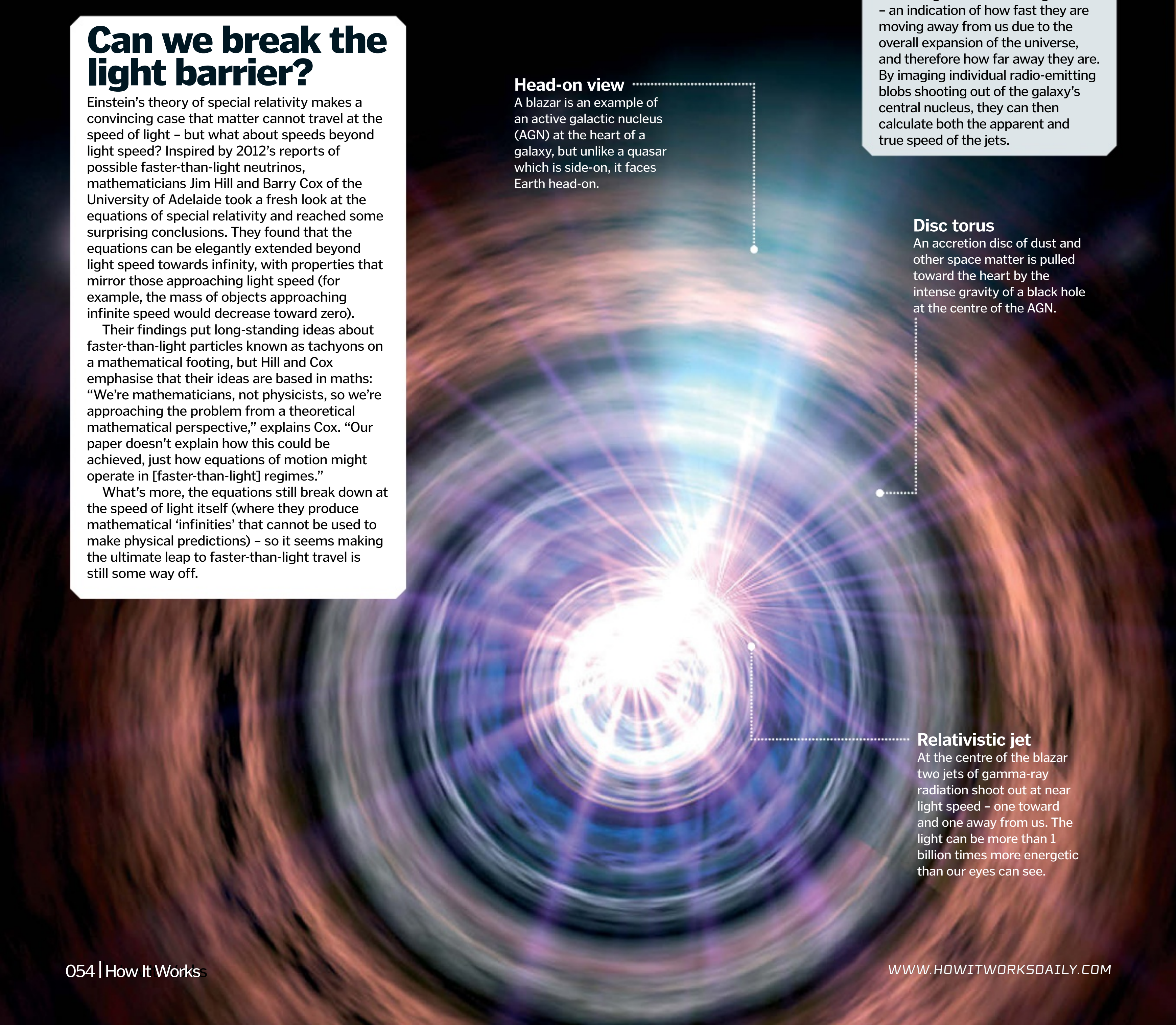
The first blazars to be discovered were initially thought to be unusual variable stars – it was only in 1968 that astronomers discovered that they emit radio waves and appeared to be embedded within faint elliptical 'host galaxies' – characteristics similar to quasars, another type of active galaxy nucleus (AGN). Today, astronomers estimate the distance to blazars by measuring the 'red shift' in light from the host galaxies – an indication of how fast they are moving away from us due to the overall expansion of the universe, and therefore how far away they are. By imaging individual radio-emitting blobs shooting out of the galaxy's central nucleus, they can then calculate both the apparent and true speed of the jets.

Can we break the light barrier?

Einstein's theory of special relativity makes a convincing case that matter cannot travel at the speed of light – but what about speeds beyond light speed? Inspired by 2012's reports of possible faster-than-light neutrinos, mathematicians Jim Hill and Barry Cox of the University of Adelaide took a fresh look at the equations of special relativity and reached some surprising conclusions. They found that the equations can be elegantly extended beyond light speed towards infinity, with properties that mirror those approaching light speed (for example, the mass of objects approaching infinite speed would decrease toward zero).

Their findings put long-standing ideas about faster-than-light particles known as tachyons on a mathematical footing, but Hill and Cox emphasise that their ideas are based in maths: "We're mathematicians, not physicists, so we're approaching the problem from a theoretical mathematical perspective," explains Cox. "Our paper doesn't explain how this could be achieved, just how equations of motion might operate in [faster-than-light] regimes."

What's more, the equations still break down at the speed of light itself (where they produce mathematical 'infinities' that cannot be used to make physical predictions) – so it seems making the ultimate leap to faster-than-light travel is still some way off.



KEY DATES
MEASURING LIGHT SPEED

Circa 1638
Galileo Galilei uses flashes from a lantern to show that light travels at least ten times faster than sound.

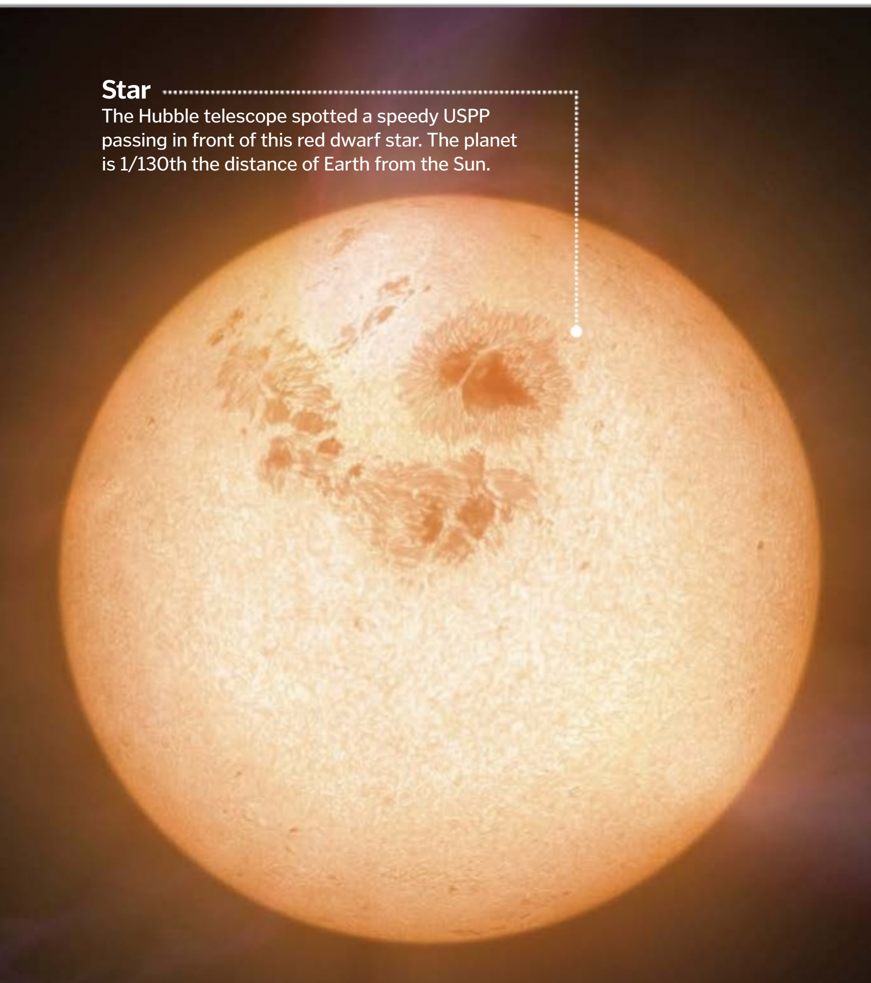
1676
Astronomer Ole Rømer (right) studies Jupiter to theorise on the limited speed of light.

1729
James Bradley uses deflections in the angle of starlight to refine the speed of light, coming close to the modern value.

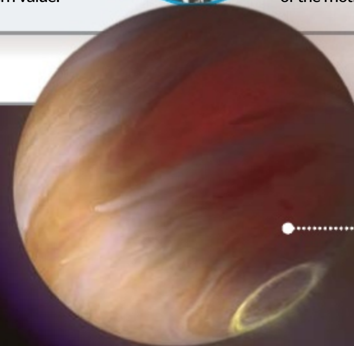
1887
Albert Michelson (left) and Edward Morley prove the speed of light is independent of the motion of its source.

1905
Albert Einstein develops the theory of special relativity to explain the fixed speed of light.

DID YOU KNOW? Escape velocity from Earth's gravity is 11.2km/s (7mi/s)



Star
The Hubble telescope spotted a speedy USPP passing in front of this red dwarf star. The planet is 1/130th the distance of Earth from the Sun.



USPP
An ultra-short period planet is so close to its star that it completes an orbit in just a few hours.

Fastest planets in space

The laws of gravity mean the closer a planet orbits its star, the faster it must move in its orbit. Our home world is moving along its orbit at an average speed of 29.8 kilometres (18.5 miles) per second, while Mercury has an even higher top speed of 59 kilometres (37 miles) per second. But these speeds are nothing compared to the fastest-moving planets in our galaxy – so-called ultra-short period planets, or USPPs, which orbit their stars in just a few hours. The fastest-known planet of this type, called Kepler-70b, is thought to be the exposed solid core of a planet that was once like Jupiter, and orbits its star at an average of 272 kilometres (169 miles) per second. No planet could ever form in such an extreme orbit, so astronomers believe that instead, these gas giants originated much farther out in their solar systems, and then spiralled inward through interacting with leftover material in clouds of planet-forming material. Some of these 'hot Jupiters' meet their doom by crashing into their parent stars. Rogue planets, kicked out of their planetary systems by the same process that creates hypervelocity stars (see over page), can also achieve great speeds.

Cosmic rays: the fastest particles

Cosmic rays are particles moving at extremely high speed through space, originating from outside our Solar System. They rarely reach the surface of Earth intact, disintegrating into showers of lighter, lower-energy particles after colliding with gases in the upper atmosphere. Nevertheless, by tracking the speed and distribution of these secondary particles (and using satellite and balloon-based detectors), astronomers can discover a surprising amount about the properties of primary cosmic rays.

Mostly atomic nuclei of hydrogen and helium – the two lightest elements – with small amounts of heavier nuclei such as lithium and beryllium, they fall into two distinct categories. Most 'normal' cosmic rays travel at speeds of around 99 per cent of the speed of light. Trillions of them bombard Earth every second and evidence suggests a significant proportion were ejected from distant supernovas.

A much rarer population of ultra-high energy cosmic rays (UHECRs), meanwhile, carry far more energy and travel at speeds a tiny fraction of a per cent below light speed itself. UHECR sources seem to lie in the same direction as distant active galaxies, and some astronomers believe they are created by fast-spinning supermassive black holes acting as natural particle accelerators.

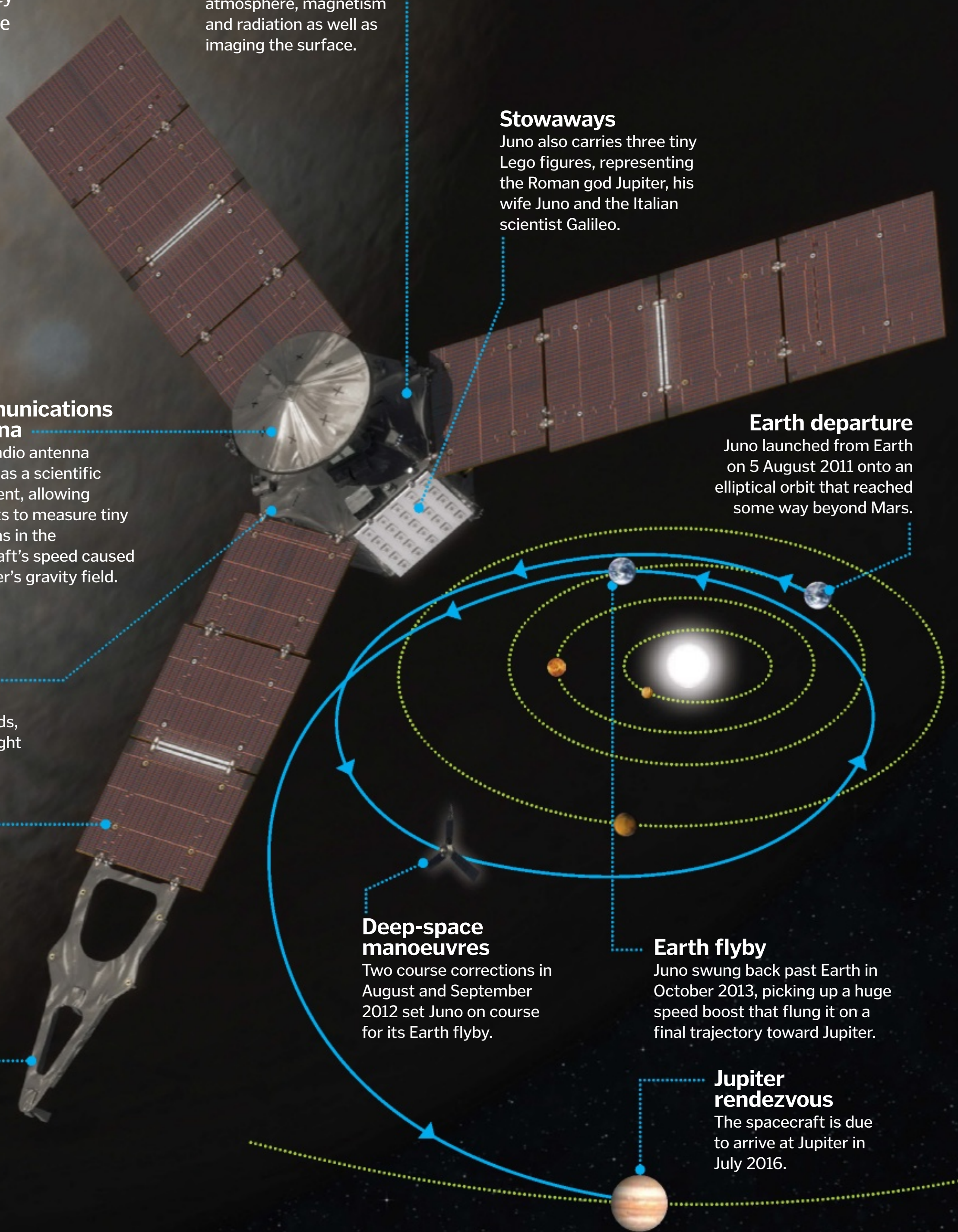
"In effect, the spacecraft steals a little of the planet's orbital momentum"

Quickest-ever spacecraft

In October 2013, the Jupiter-bound Juno spacecraft flew past Earth in a gravitational 'slingshot' manoeuvre that boosted its speed to become the fastest man-made object in the universe, shooting past us at nearly 40 kilometres (25 miles) per second relative to the Sun. Juno's slingshot made use of a technique that has been used on probes to distant planets since the 1970s, in which a spacecraft allows itself to be 'dragged in' by a planet's gravity field and accelerated, before swinging close to the planet and escaping along a different trajectory with a precisely timed burn of its rocket engines. The probe keeps the same speed relative to the planet's surface, but because the planet is moving, it can radically change its speed relative to the Solar System as a whole – in effect, the spacecraft steals a little of the planet's orbital momentum, but because the planet is so much heavier than the spacecraft, a little stolen momentum can have a dramatic effect.

Destination Jupiter

Juno's unique flight path to Jupiter will allow it to investigate unseen parts of the giant planet



STRANGE BUT TRUE
COSMIC FORCE

What's the Great Attractor?

A A CERN experiment
B Galaxy supercluster
C Brad Pitt fanzine

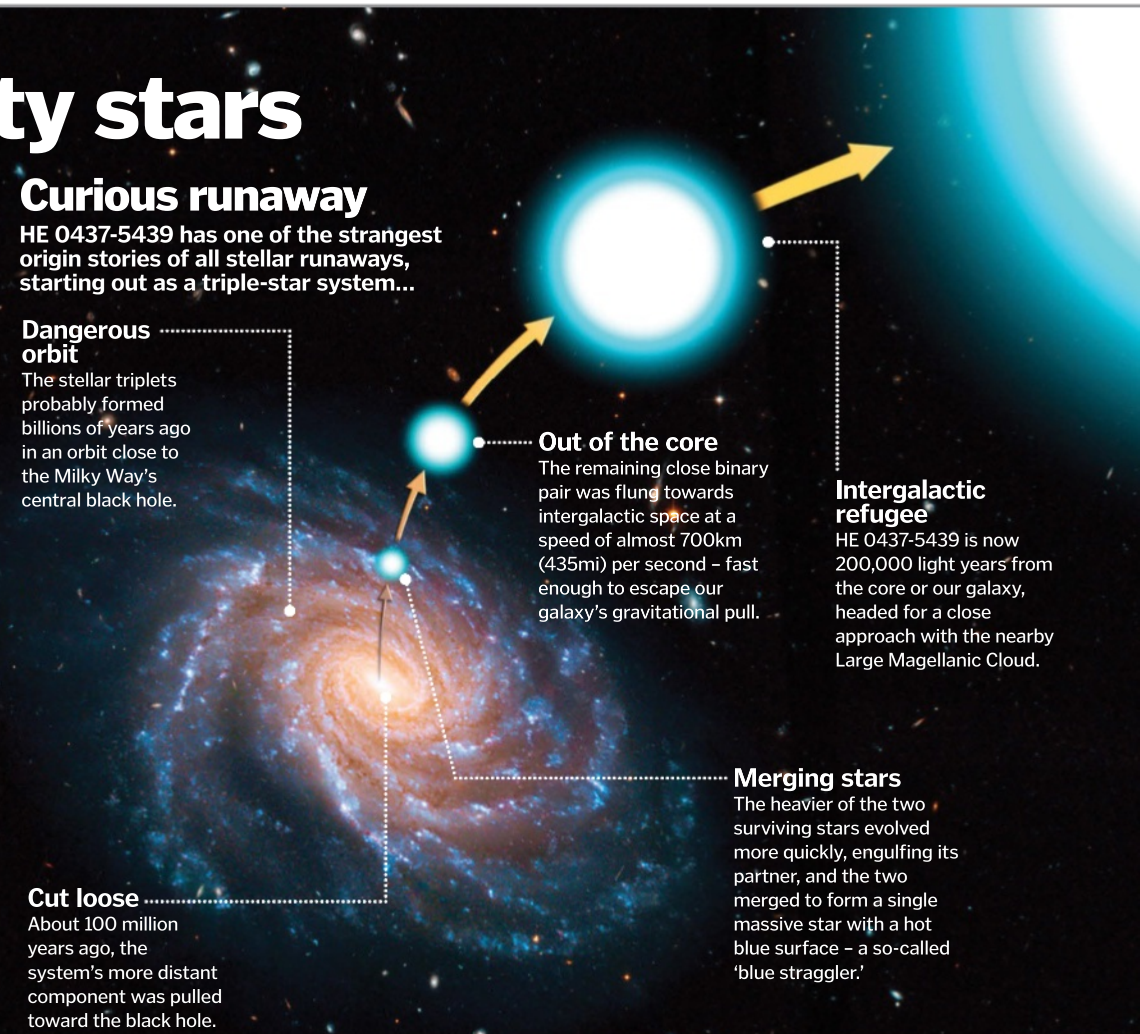
Answer:
It is the name given to a still-controversial concentration of mass in the distant universe (most likely a vast cluster of galaxies) pulling the Milky Way and every other galaxy in our neighbourhood toward it at 600km/s (373mi/s).

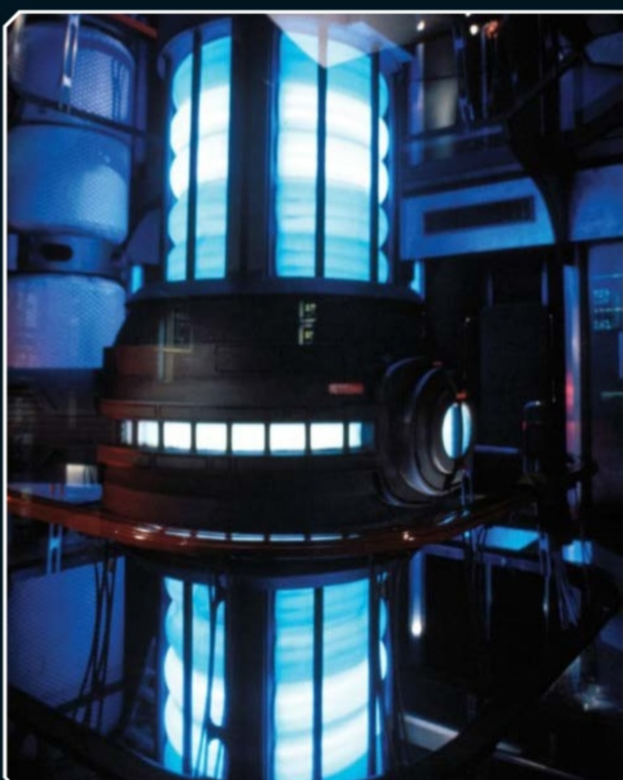
DID YOU KNOW? *The Milky Way and its galactic neighbour Andromeda are moving toward each other at 111km/s (69mi/s)*

Hypervelocity stars

Just as planets move at different speeds depending on the distance from their parent star, so stars closer to the core of our own galaxy move faster than those farther out. Our Sun, for example (roughly halfway out across the galaxy's flattened disc), moves along its orbit at about 230 kilometres (143 miles) per second. But the space above and below the plane of our galaxy is home to high-speed runaways known as hypervelocity stars. These travel at such an immense speed that they have achieved escape velocity – moving at 700 kilometres (440 miles) per second or more; the Milky Way's gravity will never be enough to slow them down.

The paths of these hypervelocity stars can often be traced back to the centre of the Milky Way, and one popular explanation is that they can be produced when one member of a binary star system is catapulted free after a close encounter with the central black hole. However, not all hypervelocity stars come from this region, so there may be several mechanisms at work. Another theory is that hypervelocity stars have been 'cut loose' from tightly bound binary systems after their more massive partners have destroyed themselves in supernova explosions.





Warp factor: fact or fiction?

Einstein's theory of special relativity suggests that it's impossible to move across space faster than the speed of light (or at least, to pass through the light-speed barrier), but could future space pioneers find ways to overcome this problem? One option would be to make use of the time dilation effect; time would flow more slowly for the crew on board a spacecraft that is moving at relativistic speeds, perhaps allowing them to travel across many light years in what, for them, would seem like only a few months.

But Einstein's general theory of relativity, which demonstrates that space-time is a four-dimensional 'manifold' that can be warped and distorted, offers another alternative – the 'warp drive'. First outlined in 1994 by Mexican physicist Miguel Alcubierre, such a device would involve moving a 'bubble' of normal space across great distances by compressing the region of space-time ahead of it and expanding the region behind it. A spacecraft inside the bubble could move at normal speeds relative to its immediate surroundings, while the bubble itself could move at faster-than-light speeds without actually breaking Einstein's rules.

NASA scientist Harold 'Sonny' White has since shown a doughnut-shaped region of distorted space-time could radically reduce the energy needs of a warp drive, and although the practical challenges remain huge, White's team at the Johnson Space Center have begun experiments to demonstrate warp effects at a micro level, which might one day be upscaled. So there's still hope for a real-life Starship Enterprise yet…

1. SMALL

DRAGONSat
Developed at two universities in Texas, this comes as a pair and its primary objective is to research autonomous satellite docking in orbit.

2. SMALLER

MEPSI
NASA's Micro-Electromechanical-based Picosat Satellite Inspectors experiment comprised two cubes joined by a tether.

3. SMALLEST

CubeSat
Over 100 of these have been sent into low-Earth orbit since 1999 and they have now become the de facto design for nanosatellites worldwide.

DID YOU KNOW? *The first CubeSat proposed in 1999 was based on the pioneering spacecraft Sputnik*

Nanosatellites explained

How are these pint-sized space explorers levelling the astronomy playing field?

Much the same as cars, satellites come in all shapes and sizes, so in that regard the CubeSat would be the Smart Car of the satellite world.

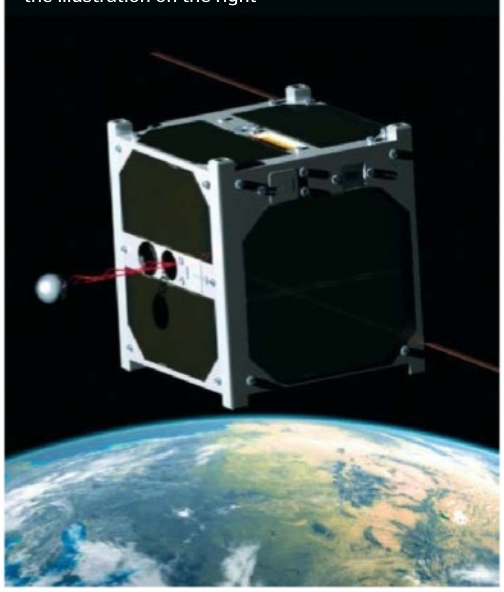
The standard model is a cube of just ten centimetres (3.9 inches) which weighs no more than a 1.3 kilograms (2.9 pounds), although this design is increasingly being modified.

There are many advantages to going small when it comes to building a satellite. Costs are dramatically reduced and the turnaround time from inception to launch can be a matter of months. It also means that universities, governments with a low budget and other private enterprises can operate them from ground stations anywhere in the world.

Virtually all CubeSats are transported into space on Poly-PicoSatellite Orbital Deployers, or P-PODs, which can hold up to three cubes per trip. The P-POD, developed at California Polytechnic State University, has been designed to be mounted to most rockets as a secondary payload, again helping to reduce launch costs.

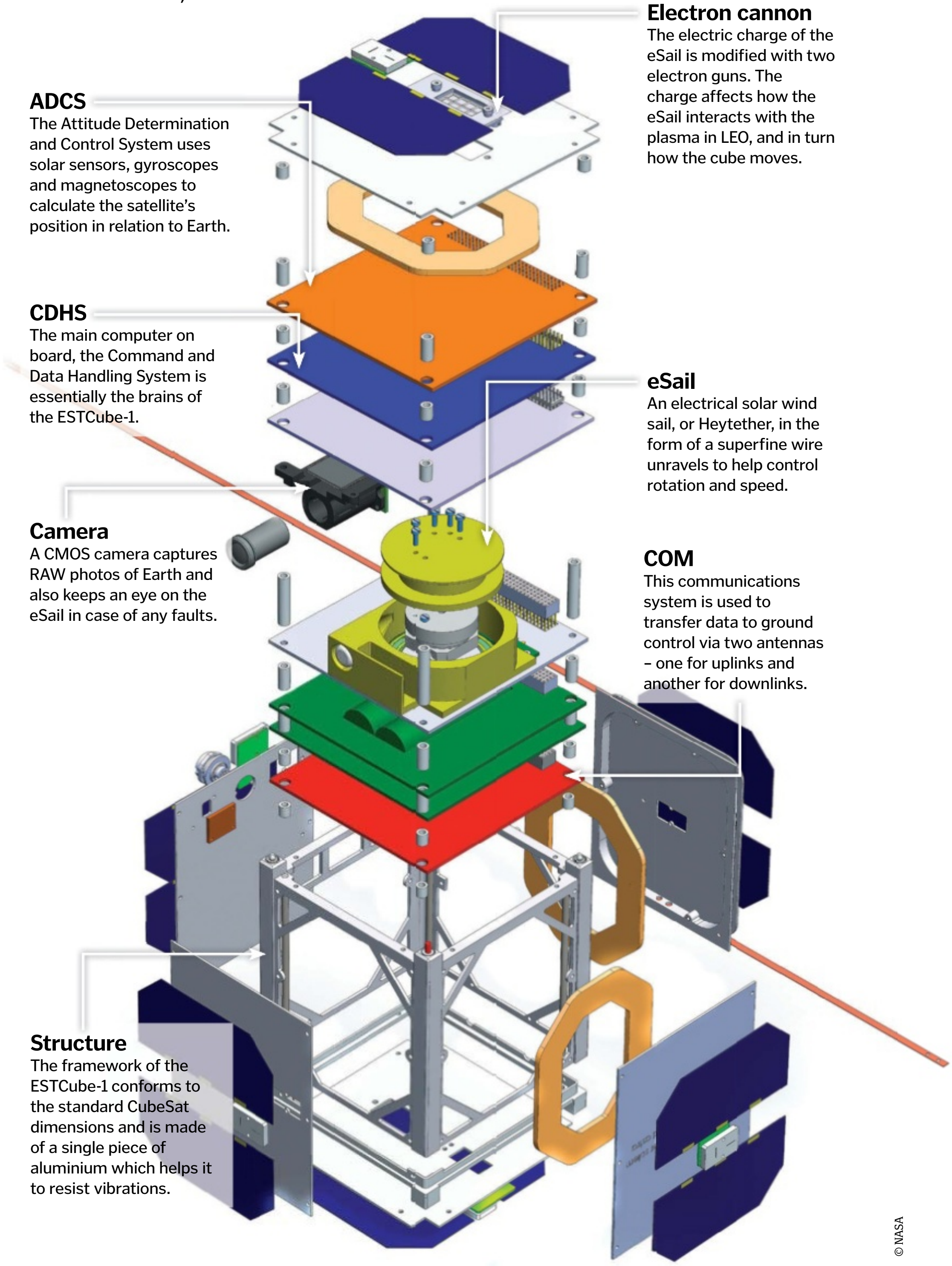
As well as offering invaluable hands-on experience for tomorrow's space engineers, CubeSats are also the perfect testbed for new scientific instruments before trialling them on bigger, more expensive satellites.

A rendering of the ESTCube-1's exterior – it's dissected in the illustration on the right



Inside the ESTCube-1

Marvel at how much technology is packed into Estonia's first-ever satellite, launched in 2013



"Their existence wasn't proven until 1993 when the Galileo spacecraft located 243 Ida and its moon Dactyl"

Binary asteroids

The science behind the space rocks that like to travel in pairs

Binary asteroids are essentially two minor planets that share a mutual gravitational attraction. They are bound together around a common centre of mass and the smaller of the two – known as the moon – is usually around 20-40 per cent the size of its larger neighbour.

When the rate of an asteroid's spin continuously speeds up, it reaches a 'fission limit'. Beyond this point, the asteroid can no longer handle the rate of rotation as a single entity and particles begin to break off until it splits into two. In astronomy this is known as the YORP effect, originally theorised by scientists Ivan Yarkovsky, John O'Keefe, VV Radzievskii and Stephen Paddack.

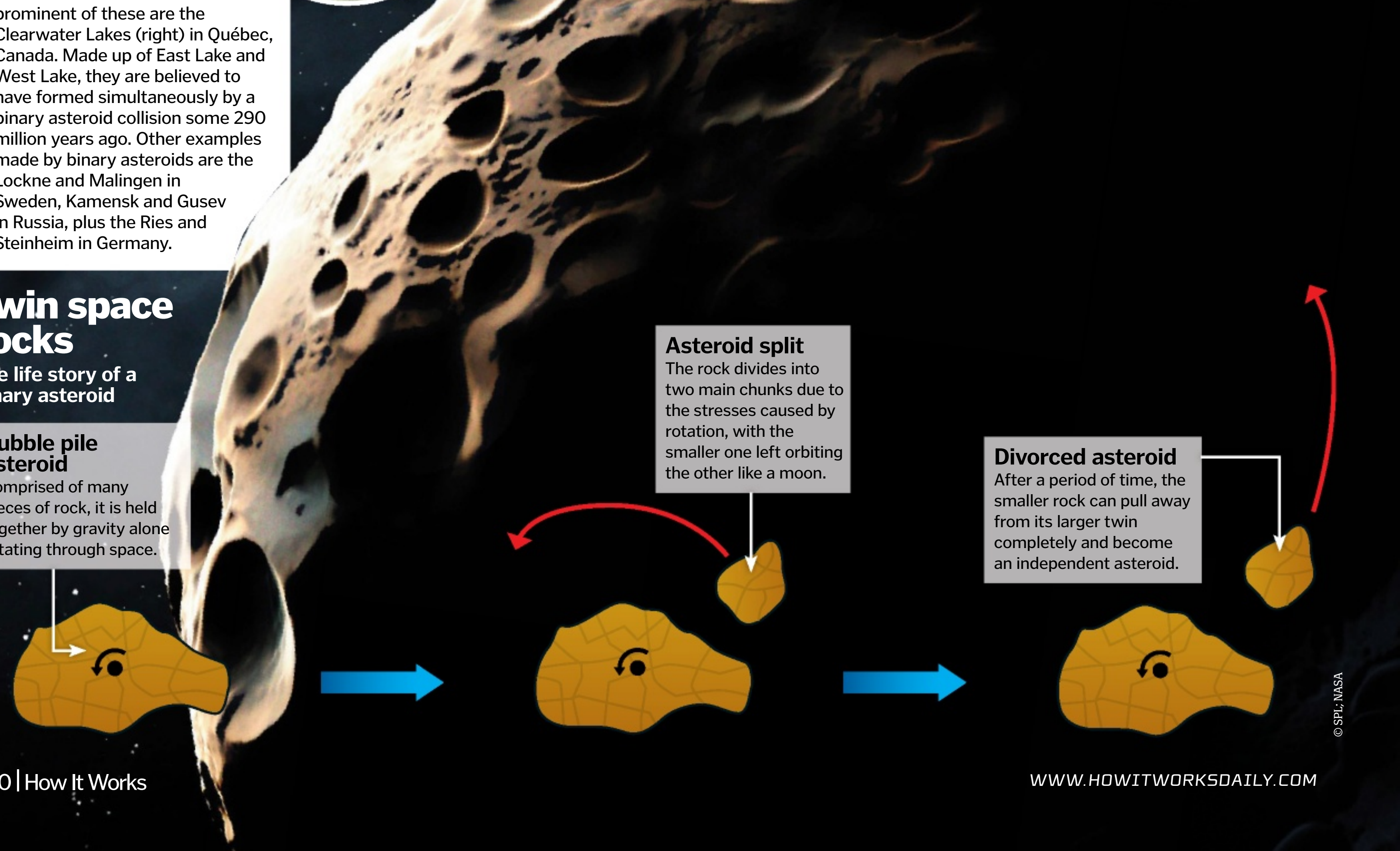
There are two types of binary asteroid: NEAs (near-Earth asteroids) and MBAs (main belt asteroids) which can travel in either spectroscopic or eclipsing lines. The former is where they are too close to be divided into separate points, while the latter is where the objects pass in front of each other.

Their existence wasn't proven until 1993 when the Galileo spacecraft located 243 Ida and its moon Dactyl in the asteroid belt. It is estimated that around 15 per cent of all NEAs and MBAs less than ten kilometres (six miles) in size are binary.

The main methods used to locate binary asteroids are by direct imaging from large aperture telescopes to spot MBAs and radio detection to find NEAs. Further research has shown there to be a possibility of ternary – or triple – asteroids, as well as 'divorced binaries', which is when a pair of asteroids lose their gravitational attraction and drift apart from each other.

Paired craters

There are many hollows in the Earth made from bolide impacts, with the largest being the 300-kilometre (186-mile) Vredefort Crater in South Africa. Paired impact craters, however, are much rarer, comprising only about three per cent of the world's craters. The most prominent of these are the Clearwater Lakes (right) in Québec, Canada. Made up of East Lake and West Lake, they are believed to have formed simultaneously by a binary asteroid collision some 290 million years ago. Other examples made by binary asteroids are the Lockne and Malingen in Sweden, Kamensk and Gusev in Russia, plus the Ries and Steinheim in Germany.



Binary asteroids are rare, yet evidence exists of binary collisions on Earth

Twin space rocks

The life story of a binary asteroid

Rubble pile asteroid
Comprised of many pieces of rock, it is held together by gravity alone rotating through space.

Asteroid split
The rock divides into two main chunks due to the stresses caused by rotation, with the smaller one left orbiting the other like a moon.

Divorced asteroid
After a period of time, the smaller rock can pull away from its larger twin completely and become an independent asteroid.

DID YOU KNOW? *Rainbows – moonbows included – are actually fully circular; this can be seen if viewing them from the air*

Midair satellite launches

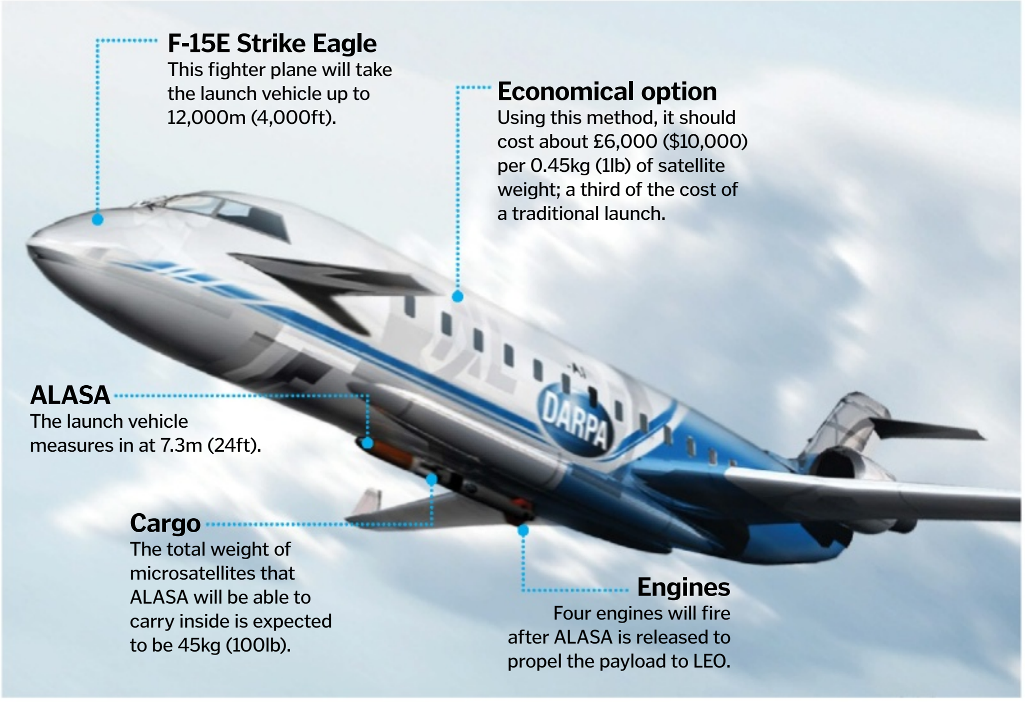
Why sending off satellites from a plane offers many benefits over land-based launch pads

Planning is well underway on a launch vehicle that will slash the cost of launching a satellite by doing it from the air rather than the ground.

Boeing and the Defense Advanced Research Projects Agency (DARPA) have joined forces to create a machine that will strap onto the underside of a modified F-15E aircraft. Upon reaching 12,000 metres (40,000 feet) the Airborne Launch Assist Space Access (ALASA) will get jettisoned and then use its own four engines to enter a low-Earth orbit (LEO), where it will release its payload of microsatellites.

The benefit of this construction is that it should save 66 per cent on each satellite launch by not having to use and discard a fuel tank and engine. Another big benefit is that the satellites can be sent up from standard runways all over the world, rather than a few limited launch pads, truly democratising space exploration.

The project will run until 2015 by which time Boeing will have built 12 ALASA vehicles.



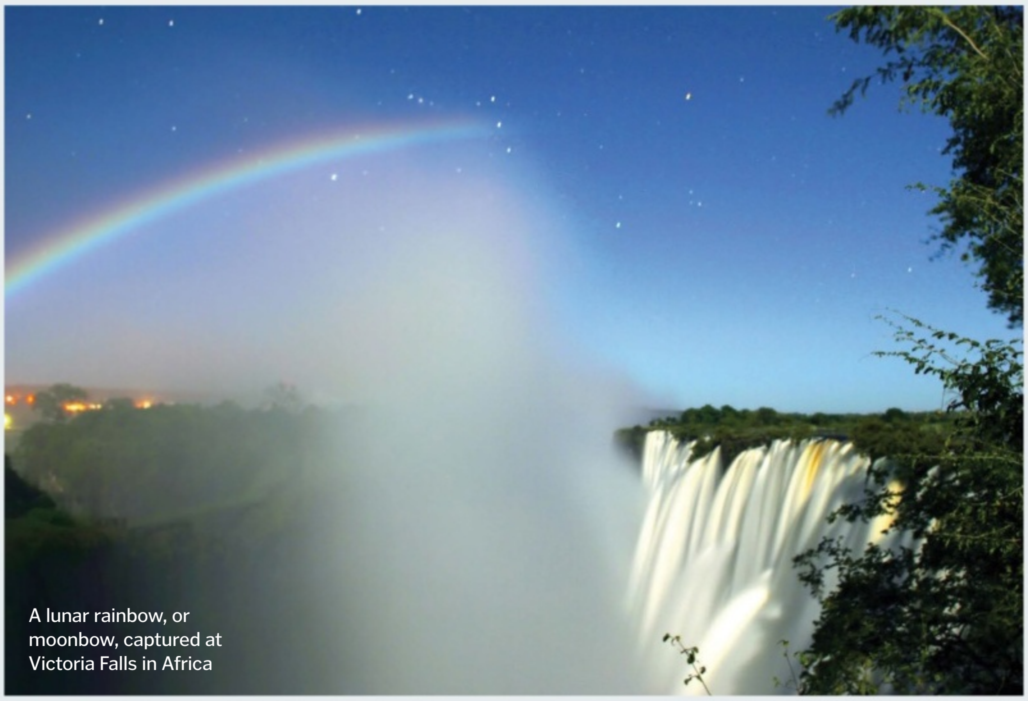
Where do moonbows come from?

How these beautiful nocturnal rainbows differ from their daytime cousins

For most people, a rainbow is an image exclusively associated with daytime. It is well known that rainbows occur when sunlight refracts off moisture drops in the air, which is why they often appear during and after rainstorms. The change of angle when the light slows as it travels through the water droplets causes the full prism of light to appear, all the way from red to purple.

However, in certain places, moonbows can occur. This is where rainbows are created by moonlight shining through moisture droplets in the atmosphere. As moonlight is much weaker than sunlight, the phenomenon is much fainter than rainbows, but nevertheless provide an incredible sight.

Some of the most vibrant and reliable moonbow sightings appear in Yosemite National Park, USA, during late-spring and early-summer, but they can appear anywhere that a bright Moon catches moisture, such as after a rain shower or near a waterfall.

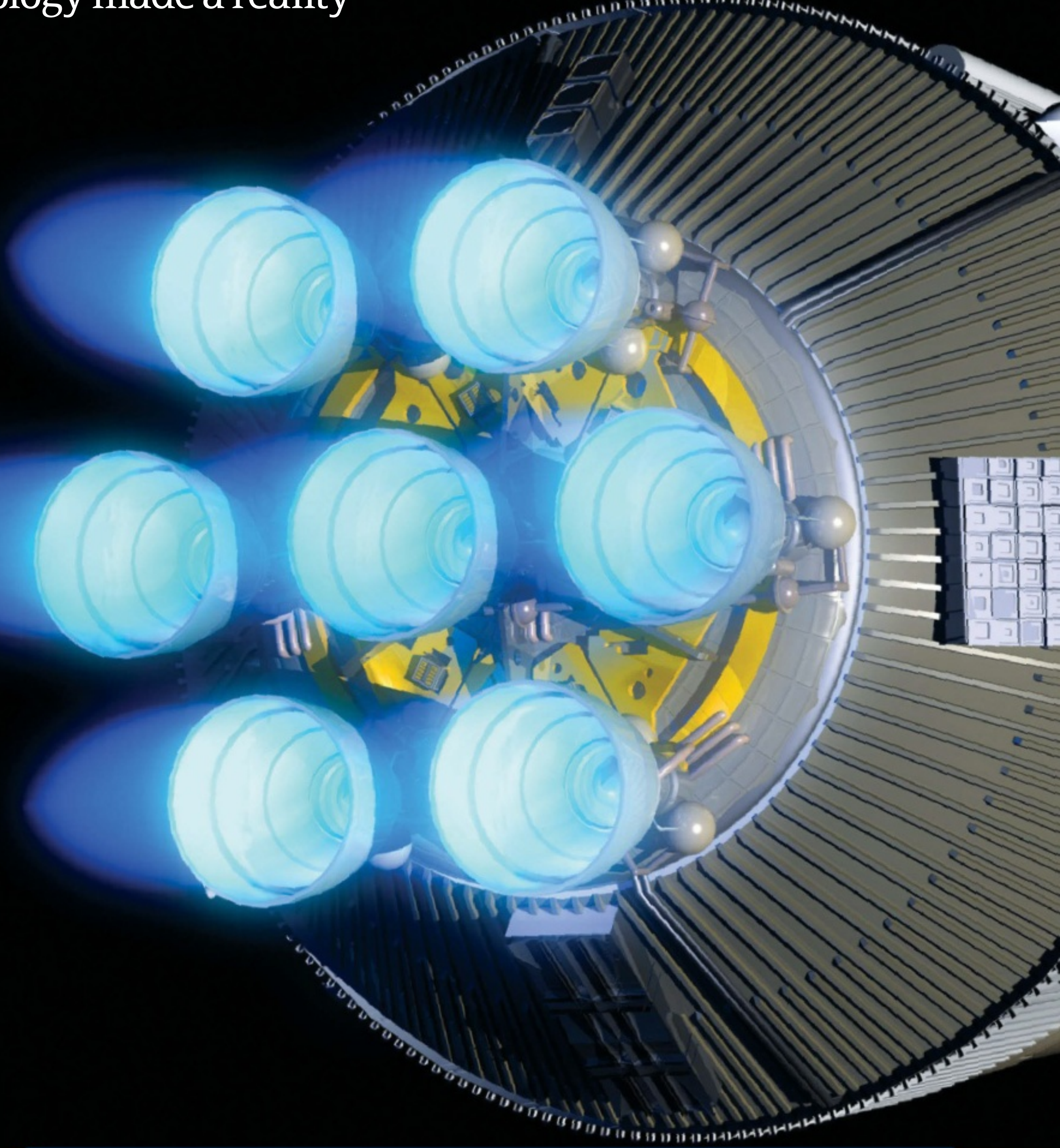


A lunar rainbow, or moonbow, captured at Victoria Falls in Africa

"The main benefit of ion thrusters is that they are able to propel rockets at a much faster pace"

How ion thrusters power spacecraft

The incredible sci-fi technology made a reality



Ion propulsion studies began in the 1950s, with NASA's Glenn Research Center engineering the earliest ion thrusters for rocket propulsion.

In the system, electrons get pushed into the thruster via a cathode tube. These electrons, which have an innate negative charge, come into contact with the propellant – typically the noble gas xenon – in the discharge chamber, drawn by strong electromagnets. When a free electron hits a neutral atom from the propellant, the xenon breaks into two negative electrons and a positive ion.

The ions then get forced into ion optics, which are electrodes that contain thousands of coaxial apertures. The end that is closer to the exit is negatively charged and the end closer to the rocket is positively charged. The positive ions stream toward the negatively charged end of the apertures, get compressed and form an ion stream. This ion stream then shoots out of the end of the thruster, providing the force to propel the rocket.

In order to keep the overall system neither positive nor negative, a cathode tube called a neutraliser pumps a stream of negatively charged electrons into the ion stream once it has been expelled to mix with the positively charged ions and balance out the whole process so the exhaust remains neutral.

The main benefit of ion thrusters is that they are able to propel rockets at a much faster pace than a chemically powered rocket. The now-retired Space Shuttle could travel at a top speed of 28,000 kilometres (17,400 miles) per hour, but an ion thruster allows for a speed of 322,000 kilometres (200,000 miles) per hour!

The downside is that, unfortunately, the amount of thrust generated by ion propulsion is minuscule. An ion thruster can only create as much as 0.5 Newtons (0.1 pounds) of force, which is about as much as holding ten small coins (20 pence or quarter dollar) in your hand. Therefore, acceleration is extremely slow but it can continue over a very long period of time.

Longer, stronger and faster

The two key benefits of an ion thruster are its longevity and its ability to propel rockets much faster than it has ever been possible to do.

NASA's Evolutionary Xenon Thruster (NEXT) is one of the most advanced thrusters around. It ran continuously for 48,000 hours – more than five and a half years – in a test to discover just how long these units can provide energy.

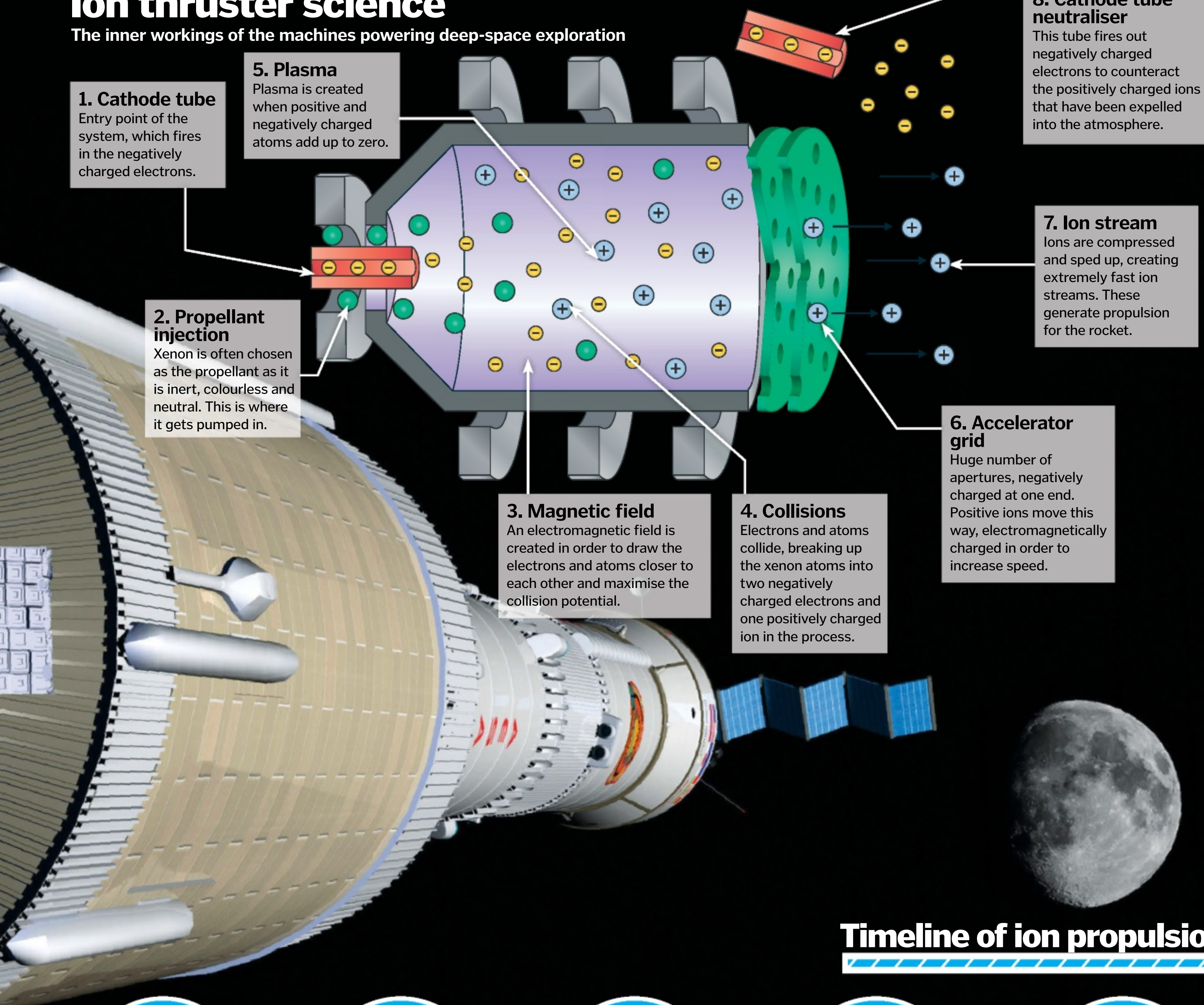
Over the course of the trial, NEXT only used 870 kilograms (1,900 pounds) of fuel, which is less than a tenth of the fuel consumption of a traditional thruster, which would have used in the range of 10,000 kilograms (22,000 pounds) of fuel.

The weight saving will allow either smaller spacecraft to undertake missions or larger craft to run for much longer than ever before.

DID YOU KNOW? *Plasma is often known as the fourth state of matter and is the most common state in the universe*

Ion thruster science

The inner workings of the machines powering deep-space exploration



1. Cathode tube
Entry point of the system, which fires in the negatively charged electrons.

2. Propellant injection
Xenon is often chosen as the propellant as it is inert, colourless and neutral. This is where it gets pumped in.

3. Magnetic field
An electromagnetic field is created in order to draw the electrons and atoms closer to each other and maximise the collision potential.

4. Collisions
Electrons and atoms collide, breaking up the xenon atoms into two negatively charged electrons and one positively charged ion in the process.

5. Plasma
Plasma is created when positive and negatively charged atoms add up to zero.

6. Accelerator grid
Huge number of apertures, negatively charged at one end. Positive ions move this way, electromagnetically charged in order to increase speed.

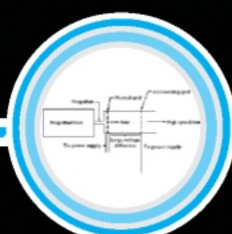
7. Ion stream
Ions are compressed and sped up, creating extremely fast ion streams. These generate propulsion for the rocket.

8. Cathode tube neutraliser
This tube fires out negatively charged electrons to counteract the positively charged ions that have been expelled into the atmosphere.

Timeline of ion propulsion

1932
German inventor Dr Wernher von Braun is given a grant to look into the possibility of running electric-propulsion rocket engines.

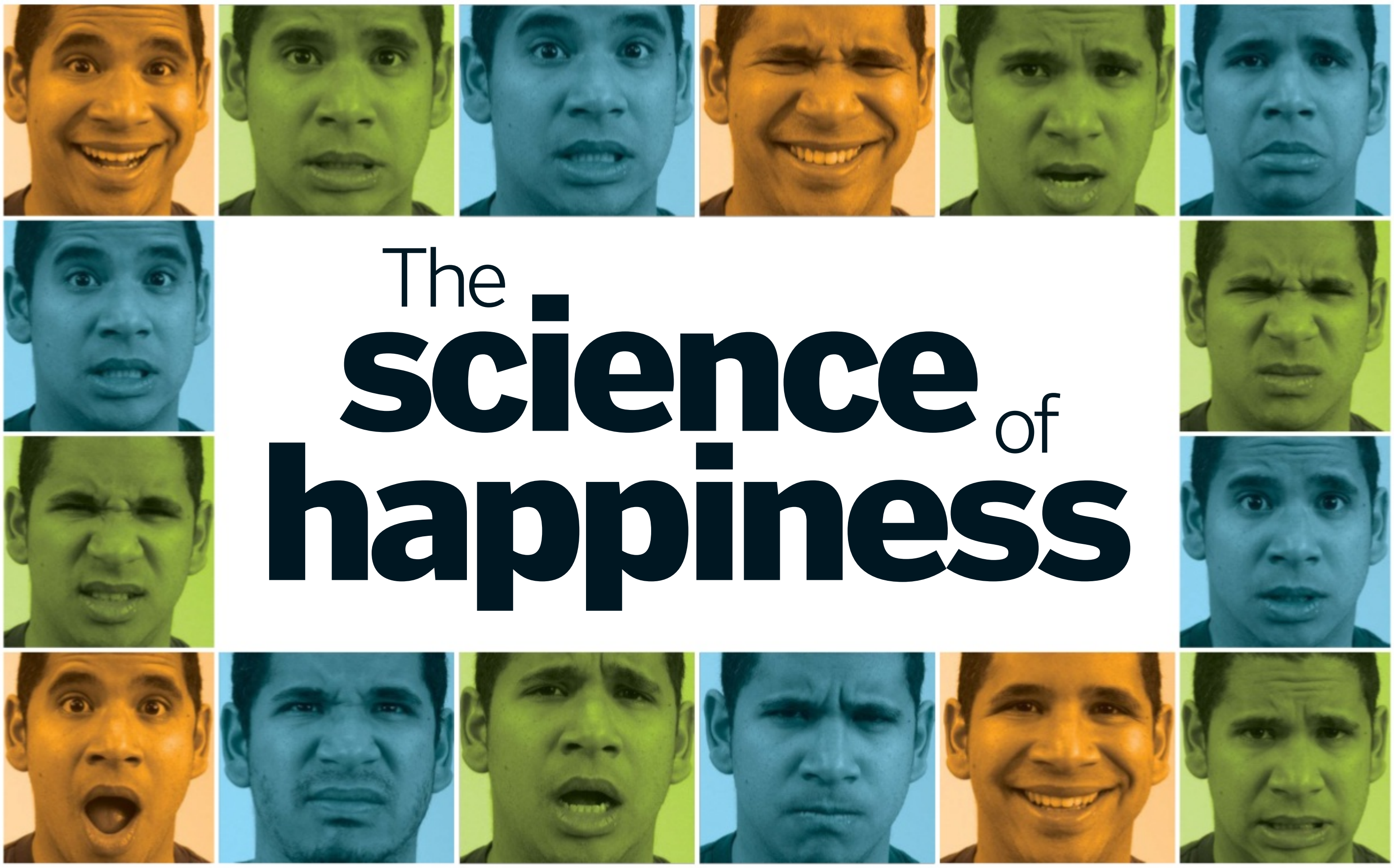
1946
Dr Ernst Stuhlinger observes a V-2 rocket travel 190km (120mi) and, after the war, helps Von Braun build a long-range rocket for the US Army.



1959
One of the first ion engines to be created is at NASA. It is powered by caesium and based on designs drawn up by Stuhlinger.

1992
The Jet Propulsion Laboratory and NASA collaborate to develop a xenon-powered ion engine – the model for the modern-day ion thruster.

1998
Ion thrusters are the main source of power on Deep Space 1, a three-year mission that involves a rendezvous with Comet Borrelly.



The science of happiness

Human emotions are governed by a complex mix of chemicals and electricity – learn all about our moody biology now…

The human brain weighs just over a kilogram (2.2 pounds) and plays host to an estimated 86 billion neurons, and at least as many supporting glial cells. Signals are transmitted along each nerve electrically, by gradients of charged ions, and each neuron makes hundreds of connections to those around it.

At each of the 300 trillion synapses in the human brain, chemicals known as neurotransmitters relay messages from one nerve to another. Each neurotransmitter has a set of corresponding receptors, which can be activatory or inhibitory, helping nerves to fire, or suppressing their activity. This enormous chemical and electrical system provides the complex network that enables us to feel emotion, from the all-consuming addiction of love, to the raw devastation of grief.

Techniques like functional magnetic resonance imaging (fMRI) have helped reveal areas of the brain involved in processing different emotional responses. This data, in combination with case studies of patients with damage to certain areas of their brains, and information gathered from investigations in animals, has enabled us to draw up a map of emotional connections in the body.

A notable area of the brain when it comes to mood is the limbic system (see opposite) – a small cluster of interconnected regions involved in memory storage and decision-making. The limbic system is directly connected to the olfactory bulb, which processes incoming smell signals from the nose, providing the biological link that allows odours to recall a memory. Recent research at the Kavli Institute for Systems Neuroscience in Norway suggests smell-based memories are triggered with the activation of corresponding brain waves to those experienced on initially experiencing the scent.

The nucleus accumbens links the limbic system to other areas of the brain also involved in the processing of emotion. For instance, the basal ganglia, at the base of the forebrain, has been well studied for its role in the planning and co-ordination of movement, but certain areas also light up in response to positive emotional stimuli and are thought to be involved in reward and reinforcement. Damage to part of the basal ganglia, known as the ventral pallidum, causes anhedonia – the inability to experience pleasure. The orbitofrontal cortex, located above the eyes, also activates in response to positive experiences, and is thought to play a role in evaluating reward versus punishment.

Another approach to the study of complex emotions like happiness is to break them down into

Compound emotions

New research by Ohio State University has found that we may have as many as 21 distinct and complex emotional expressions – a few demonstrated in the images above. Hybrid emotions include being 'angrily surprised' or 'happily disgusted' and appear when conflicting feelings are experienced simultaneously. For instance, you may be sad something has ended but happy that you have experienced it. Previous studies suggested that we only had six emotions.

5 TOP FACTS
GET HAPPY!

Wear a smile
1 Your body influences your emotions: frowning can make you feel angry, even when you aren't, so forcing a smile even if you don't feel like it can help improve your mood.

Strike a hero pose
2 Psychologist Amy Cuddy has shown that 'power posing' before a challenging situation, like a job interview, raises testosterone, lowers cortisol and boosts confidence.

Laugh out loud
3 The act of laughing triggers the release of endorphins, which act not only as natural painkillers, but also induce feelings of euphoria, so comedy really is good for us.

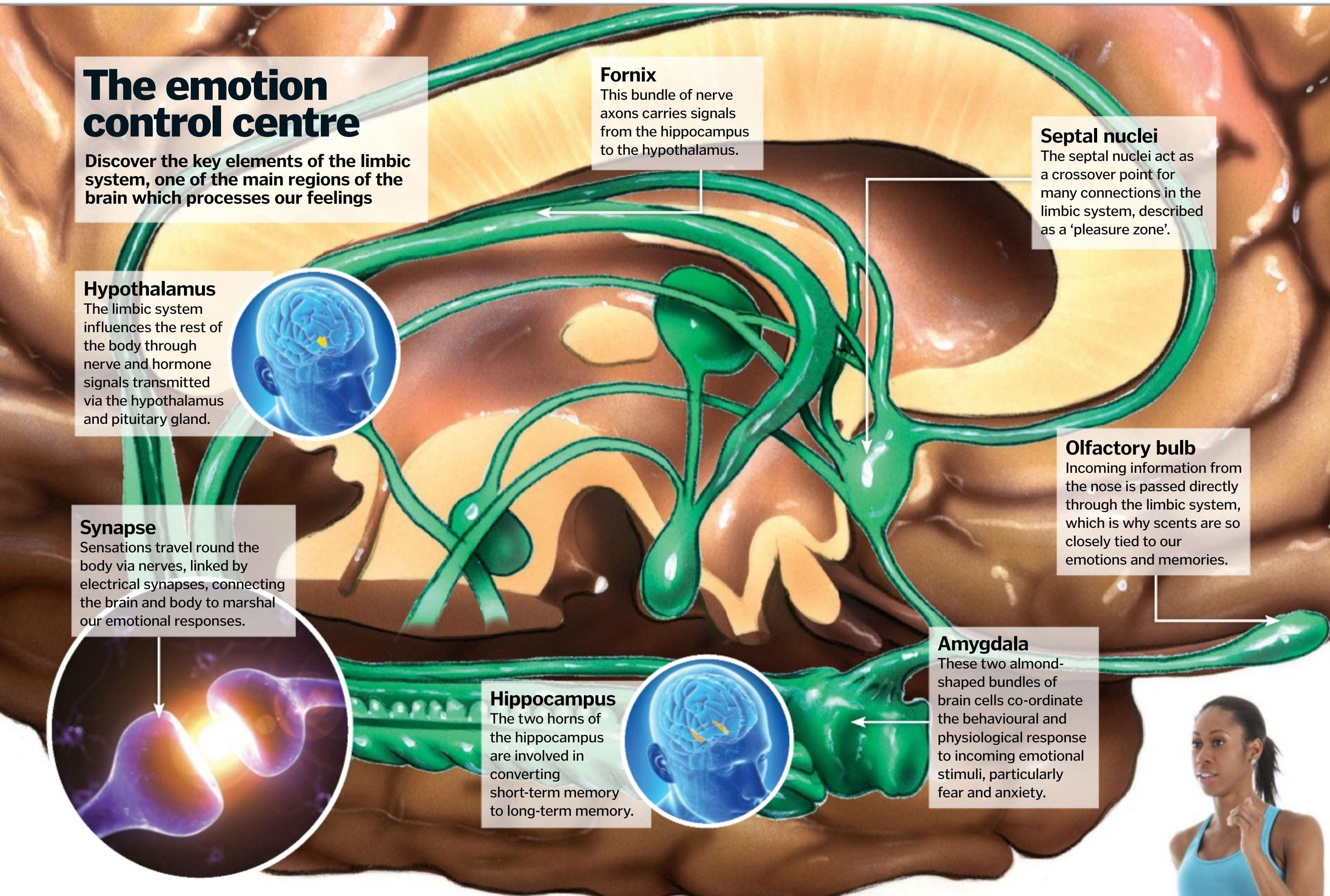
Sniff out happiness
4 The olfactory bulb is connected to the limbic system and smell plays a role in both emotion and memory. Familiar scents can provide an instant mood boost.

Eat the right food
5 Omega-3 fats, commonly found in oily fish and other seafood, are connected with serotonin levels, while folic acid from green vegetables may help fight off depression.

DID YOU KNOW? *Serotonin is found in some insect venom and plant spines; it can cause pain, tingling and nausea*

The emotion control centre

Discover the key elements of the limbic system, one of the main regions of the brain which processes our feelings



Fornix
This bundle of nerve axons carries signals from the hippocampus to the hypothalamus.

Septal nuclei
The septal nuclei act as a crossover point for many connections in the limbic system, described as a 'pleasure zone'.

Hypothalamus
The limbic system influences the rest of the body through nerve and hormone signals transmitted via the hypothalamus and pituitary gland.

Olfactory bulb
Incoming information from the nose is passed directly through the limbic system, which is why scents are so closely tied to our emotions and memories.

Synapse
Sensations travel round the body via nerves, linked by electrical synapses, connecting the brain and body to marshal our emotional responses.

Amygdala
These two almond-shaped bundles of brain cells co-ordinate the behavioural and physiological response to incoming emotional stimuli, particularly fear and anxiety.

Hippocampus
The two horns of the hippocampus are involved in converting short-term memory to long-term memory.

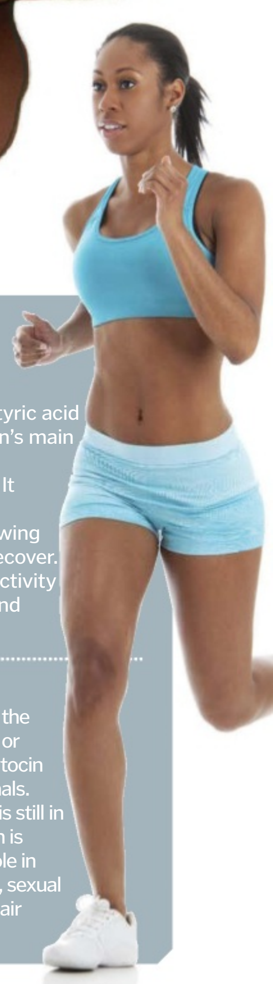
How do drugs alter our mood?

Humans have been modifying their brain chemistry for medical, religious and recreational purposes for centuries, despite the many risks. Stimulants like caffeine, nicotine, cocaine and amphetamine affect the release of the fight-or-flight chemicals adrenaline and noradrenaline, increasing alertness. While euphoriants like MDMA cause a surge of serotonin, which in turn leads to the release of bonding hormone oxytocin, resulting in a sense of euphoria.

Depressants, including sedatives, hypnotics and alcohol, work on the GABA receptor system to dampen brain activity. GABA is an inhibitory neurotransmitter, and blocks nerve activity, resulting in relaxation and reduced anxiety. Some depressants have anti-convulsant effects, so are used as a treatment for epilepsy.

Opioids also modulate nerve signals. Opium, along with related drugs like morphine, have a similar structure to natural endorphins and bind to their receptors in the brain and spinal cord, resulting in pain relief and euphoria.

Emotional messengers



Dopamine
This neurotransmitter feeds the reward pathway in the brain and is involved in motivation, drive, pleasure and addiction. Abnormally high levels of dopamine are linked to loss of contact with reality, delusions and lack of emotion, while low levels are linked to addictive behaviour and risk taking.

Noradrenaline
Related to adrenaline, this neurotransmitter is a stress hormone that co-ordinates the fight-or-flight response. It mediates many of the physical components of emotion, including raised heart rate, and also acts in the brain to enhance alertness, cognition and decision-making behaviour.

GABA
Gamma-aminobutyric acid (GABA) is the brain's main inhibitory neurotransmitter. It subdues nerve transmission, allowing neurons time to recover. Increased GABA activity reduces anxiety and stress.

Serotonin
First recognised for its ability to constrict blood vessels, serotonin has since become widely regarded as the 'happiness hormone'. Chemically known as 5-hydroxytryptamine (5-HT), increasing the serotonin level in the brain is the main goal of medical antidepressants.

Beta-endorphin
Endorphins are natural opioids, produced in response to pain, excitement and exercise (pictured). Beta-endorphin binds to the same mu receptors as pain-relieving morphine. Present on nerves in the brain and spinal cord, they modulate neural activity, causing mild sedation, relieving pain and inducing joy.

Oxytocin
Often described as the 'bonding hormone' or 'love hormone', oxytocin is unique to mammals. Although research is still in its infancy, oxytocin is thought to play a role in intimacy, childbirth, sexual arousal, trust and pair bonding.

"Pleasure is evolutionarily ancient and is based on a chemical reward system"

smaller parts. Pleasure is evolutionarily ancient and is based on a chemical reward system that acts as a biological incentive to repeat beneficial behaviour. There are several 'reward pathways' in the brain, but the most studied is the mesolimbic pathway.

The pathway transmits dopamine signals from nerves in the middle of the brain, upward and forward, to the limbic system and the prefrontal cortex, which are involved in emotional processing. Under normal conditions, this pathway serves as a motivator for positive actions, producing pleasurable feelings that reinforce beneficial behaviour like eating high-calorie food, social interaction and reproduction. Activation of the pathway also aids in memory retention, increasing the likelihood that the action will be repeated in the future.

Unfortunately, the pleasurable feedback is so strong that abuse of the pathway is common. Many illicit substances, including cocaine, amphetamine and MDMA, affect the mesolimbic pathway, resulting in a pleasurable reward, but also contributing to habituation and addiction.

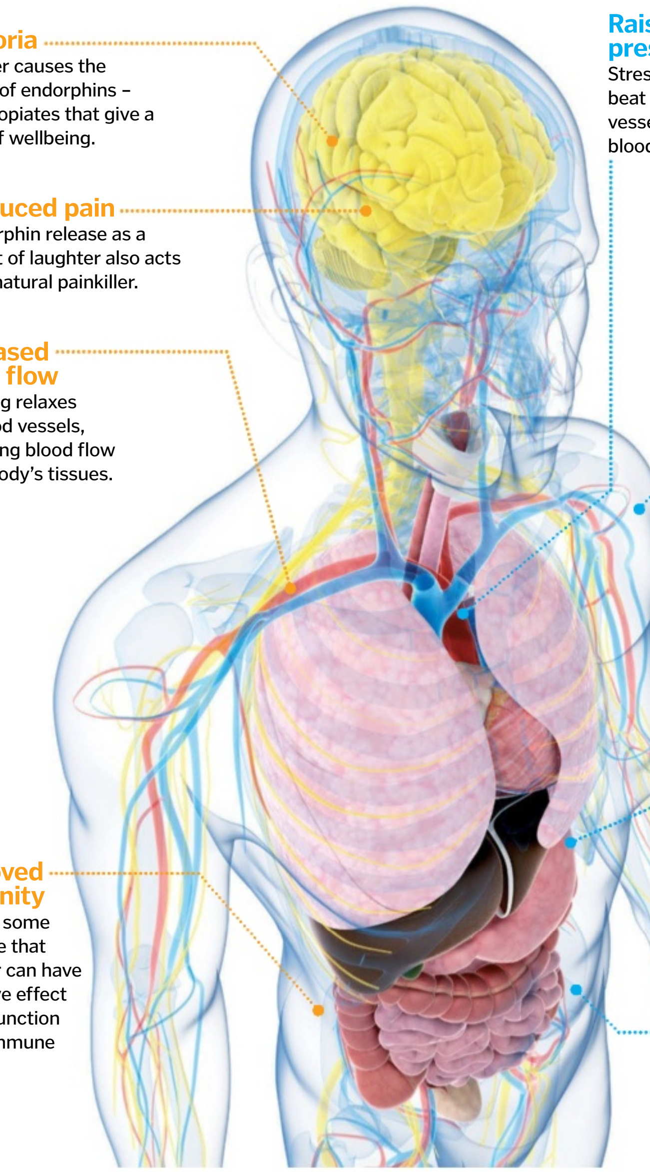
It's not all about the brain though. The feelings associated with emotions are the result of a complex mixture of incoming sensory messages that come from all over the body.

Can we fake a smile?

Faking emotions is harder than it seems. Humans are social animals and have evolved extremely good facial recognition skills – so if something isn't quite right, we are quick to notice. The muscles around our mouths are under fine voluntary nerve control, which not only provides the range of motion required for speech, but also enables us to fake a smile. But people are not easily deceived. Facial expressions involve a multitude of subtle, involuntary muscle movements, and re-creating them is incredibly difficult. The forehead and eyebrows are particularly challenging, as the muscles are mostly under subconscious control. It is hard to achieve the same expression with voluntary muscle contraction, and our eyes are often the biggest giveaway when a smile isn't genuine.

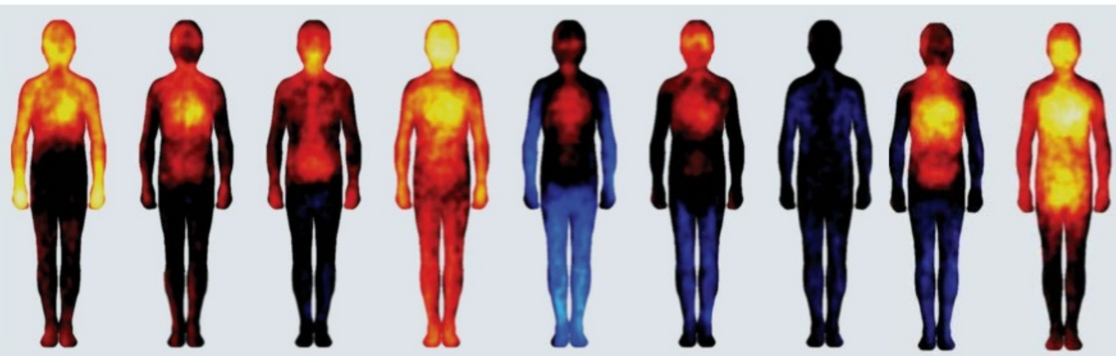
Laughter vs stress

These two opposing states have very different effects on the body, as we reveal here…



Mapping out emotions

The complex human emotions are the result of sensory signals from the rest of the body. Researchers at Finland's Aalto University charted the areas of the body most commonly associated with different feelings to produce maps of where we experience the major emotions. The images demonstrate how different emotions trigger different levels of sensation around the body. Here high levels of sensation are represented with warmer hues, and vice versa.



Can money buy you happiness?

A Yes B No C Sometimes

Answer:
Studies show that money does buy happiness, but only if you don't have too much of it. Being rich might seem appealing, but once a comfortable standard of living has been reached, additional wealth offers little improvement in mood.

DID YOU KNOW? Two-thirds of close couples can smell each other's emotions and detect a difference between fear and happiness

Emotions are often influenced by physical stimuli, be it food, behaviour or environmental factors like sunlight

The autonomic nervous system (more commonly known as ANS) is the subconscious arm of the peripheral nervous system, and is responsible for bodily functions that are not under our voluntary control, such as heart rate, digestion and sweating; it too is wired in to the limbic system.

The ANS has two distinct components with opposing functions. The sympathetic nervous system uses the neurotransmitters adrenaline and noradrenaline to prepare the body for 'fight or flight', raising the heart rate and mobilising resources to fuel the muscles. The parasympathetic nervous system uses acetylcholine to allow the body to rest and digest, slowing the heart and breathing, and diverting the blood supply to the gut.

Sensory feedback produced by the effects of the autonomic nervous system contribute to many of the familiar feelings associated with emotions. Stimulation of the heart by adrenaline and noradrenaline as part of the fight-or-flight response produces the rapid palpitations associated with anger, fear and embarrassment. Its actions on the digestive system cause 'butterflies in the stomach', and activity at the glands on the hands, feet and in the armpits, leads to sweating when nervous.

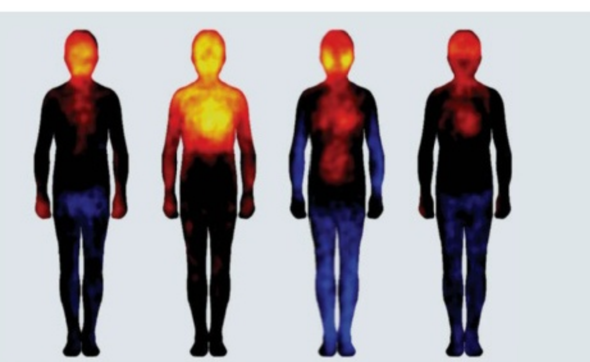
More passive emotions, like sadness or contentment, on the other hand, require little physical response, and the parasympathetic nervous system takes control of the heart, slowing its rate. Feelings of contentment and relief are often accompanied by deep, slow breathing – another indicator of parasympathetic activity.

The limbic system is also connected to the body via the hypothalamus. This small region, located on the underside of the brain, links the nervous system to the endocrine system, which produces hormones – some of which are key mediators of mood and emotion. For example, corticotropin-releasing hormone is produced in response to stress, and leads to the release of the stress hormone cortisol from the adrenal glands above the kidneys.

The regulation of emotion is not just restricted to one area of the brain – it involves almost the entire body. Reducing the bewildering complexity of human emotion down to anatomy, physiology and, ultimately, brain chemistry, might seem clinical and overly simplistic, but in reality, the fact that humans are capable of experiencing such an extraordinary range of abstract feelings is one of the greatest wonders of biology, with many chemical puzzles still waiting to be solved in this area.

Fight or flight

The autonomic nervous system is responsible for the control of heart rate, blood pressure and respiration, and governs the function of most of the internal organs. It's divided into two parts. The sympathetic nervous system is responsible for the fight-or-flight response and is behind raised heart rate, sweating, nausea and shaking associated with action-based emotions like anger and anxiety. While the parasympathetic nervous system has the opposite effect and plays a bigger role in more passive emotions like sorrow and contentment.



5 happiest countries

(based on wealth, economic growth and quality of life, 2013)

1. Norway
2. Switzerland
3. Canada
4. Sweden
5. New Zealand

3 unhappiest occupations in the UK (2014)

1. Publican
2. Elementary construction
3. Debt collection

HAPPIEST and SADDEST states in the United States

(Gallup-Healthways Well-Being Index, 2013)

HAPPIEST	SADDEST
1. North Dakota	1. West Virginia
2. South Dakota	2. Kentucky
3. Nebraska	3. Mississippi

25%

Of 129 gold medal ceremonies at the London 2012 Olympics, 25 per cent of FEMALE ATHLETES CRIED, compared to just eight per cent of male competitors

SMILIEST country Brazil

Travel app Jetpac analysed INSTAGRAM IMAGES BY COUNTRY, ranking photos based on whether the subject had a wide grin or a tight-lipped smile. Brazil finished first, while the USA lagged behind in 33rd place. The UK ranked 62nd and Japan came bottom

23 69

LIFE SATISFACTION peaks at the AGES of 23 and 69, according to the London School of Economics (2013)

1. TOXIC

Slow loris
The only toxic primates on Earth, some lorisids have venom stored in a patch on their elbows, which they licks to gain a poisonous bite for self-defence.

2. MORE TOXIC

Assassin caterpillar
This creepy-crawly is very venomous to humans. Its toxin causes internal bleeding almost immediately after contact.

3. MOST TOXIC

Box jellyfish
Often described as the most venomous animal in the world, only a tiny amount of venom delivered by its stingers can cause death.

DID YOU KNOW? *Antivenoms can take up to ten years to be approved by the World Health Organization*

A snake being milked for venom. It can either be held and forced to bite or allowed to do so on its own accord

Making antivenom

How is nature's deadliest venom transformed into its own cure?

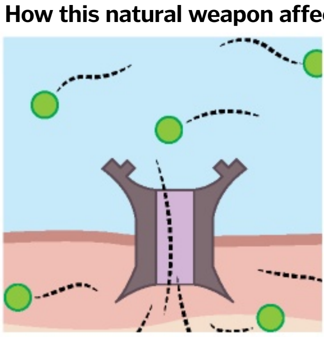
Whether it's a deadly cobra, spider or scorpion, antivenoms offer us one final lifeline against otherwise fatal stings and bites. At current estimates, snake bites alone are responsible for up to 100,000 deaths every year, so the production and development of antivenom is vitally important.

The process was devised in 1894 by French bacteriologist Albert Calmette, a student of Louis Pasteur. The poisonous animal is 'milked' for venom by gently pressing on the venom glands to test on horses, sheep or goats, etc. The chosen animal is injected with a minute amount of the venom (so little they suffer no ill effects) and its body responds by creating antibodies. These antibodies are then collected via a small blood sample taken from the animal and cooled at two to eight degrees Celsius (35.6 to 46.4 degrees Fahrenheit). A centrifuge (inset above) is then used to separate the plasma in the blood before enzymes are introduced to break down the antibody to get antivenom. Types of venom vary considerably between species so this process must be repeated for a wide range of animals.

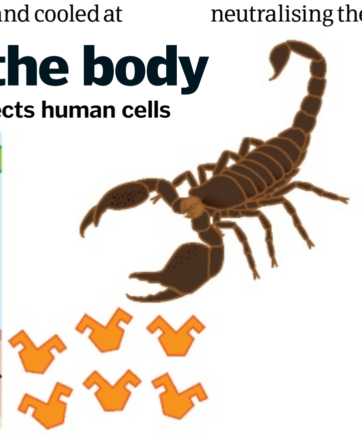
Antivenom is similar to vaccinations but has one key difference. Vaccinations are used to teach human antibodies to develop a resistance against a disease. However, the nature and ferocity of venom means the body can never create enough antibodies to fight back fast enough. Therefore, ready-made 'donor' antibodies are the perfect solution. With this backup, the body's defences can multiply and attack the venom molecules, neutralising them before they destroy cells.

Venom and the body

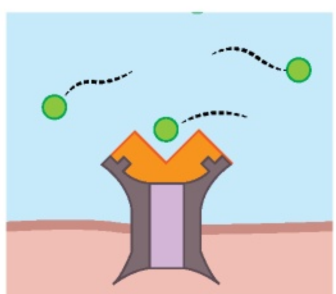
How this natural weapon affects human cells



1. Before venom
A muscle cell receives chloride ions via channels on its surface. These have a specific shape that will only allow matching molecules to pass in or out of the cell to facilitate activity.



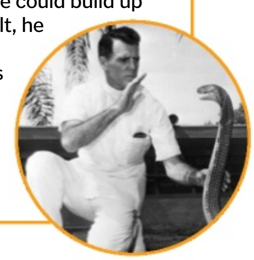
2. Venom injected
The venom – in this case, of the deathstalker scorpion – contains chlorotoxin, a protein chain that is also perfectly shaped to fit in the chloride ion channel.



3. Channel blocked
The chlorotoxin blocks chloride ions from entering or exiting the muscle cell. This stops the cell from functioning properly, causing paralysis and, if not treated, death.

Getting to know the snake whisperer

William 'Bill' Haast is probably the world's most famous snake handler. Bitten a reported 172 times, Haast was the USA's leading producer of venom for use in serums. Around 36,000 samples were sent to laboratories each year by the 'snake man'. He would milk the snakes with his bare hands and send off vials on virtually a daily basis. Very dangerously, Haast would also inject himself with venom so he could build up his natural defences. As a result, he gained an immunity to many types of snake, so transfusions from his blood helped save others. The pioneering, if unorthodox, advancer of antivenom died in 2011 of natural causes, aged 100.



> "Specific proteins and cell types can be tagged with GFP, allowing researchers to track their movements"

The photoelectric effect

Get to grips with the phenomenon that started the quantum revolution

The aptly named photoelectric effect occurs when light shining down on a metal causes a small electrical current to be produced. This happens because the energy present in the light knocks electrons from their atoms on the metal's surface.

The phenomenon, however, depends on the colour of light shone on the metal. For example, no matter how intense a red light you use, no electrons would be dislodged. Yet even a very dim blue light produces the effect.

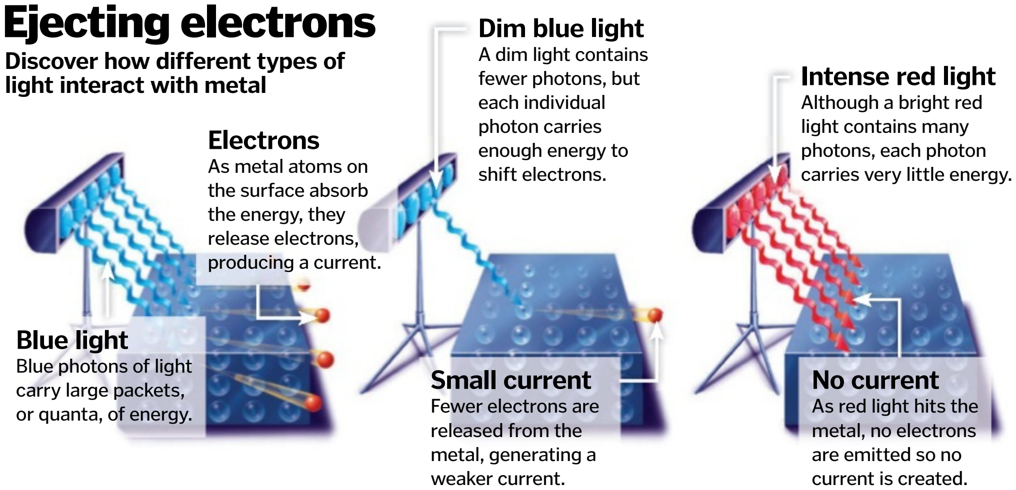
Considering light as a wave, this doesn't seem to make any sense: a brighter, bigger wave should carry more energy than a dimmer, smaller wave. Albert Einstein explained this paradox by envisioning light instead as a particle. Each particle, or photon, carries a packet of energy. Blue photons each carry enough energy to dislodge an electron. But individual red photons simply do not have enough energy to shift electrons from their atoms, no matter how many photons there are.

Providing compelling evidence that light could behave as a particle, Einstein's explanation sparked the beginnings of quantum theory, where light behaves simultaneously as a wave *and* a particle.

Today, the photoelectric effect allows solar cells to convert the Sun's energy into electric current (pictured right). It is also used to detect faint sources of light, with applications from night-vision goggles to space instruments.

Ejecting electrons

Discover how different types of light interact with metal



Green fluorescent protein and quantum dots are helping us understand cells' inner workings

Bioluminescence in nature

Hundreds of living organisms produce light, although most do not fluoresce, instead getting their glow from chemical reactions. Most of these are marine creatures and bacteria, although terrestrial invertebrates (eg fireflies, inset) and fungi can also glow. Bioluminescence serves a variety of functions. In many marine animals, it provides camouflage by allowing its bearer to blend in with the surrounding light when viewed from below. In other species it is used as a form of communication or, like the anglerfish, to draw in prey. Researchers aren't certain what the Aequorea victoria jellyfish uses its eerie GFP glow for, but some believe it may be to evade predators.

Illuminating cells

Find out how GFP and quantum dots are shedding light on medical research…

For millions of years, the Aequorea victoria jellyfish held the secret to green fluorescent protein (GFP) – a protein that absorbs the energy from the blue and ultraviolet (UV) range and re-emits it as a green light. Biologists got their hands on the glowing jellyfish in the 1960s, extracting the protein and then uncovering the gene that codes for it.

By inserting this sequence into living organisms, scientists equip them with the instructions required to manufacture GFP, highlighting how genes are expressed in everything from bacteria to human cells. Specific proteins and cell types can be tagged with GFP, allowing researchers to track their movement and interaction. Tagging the HIV virus with GFP, for instance, shows how the infection spreads.

A similar effect can be achieved with quantum dots – nanoscale semi-conductor crystals which also fluoresce under UV light. The dots can be made in many different colours and bound to proteins, allowing scientists to observe complex biological interactions.

Recently, surgeons wearing special goggles identified and removed cancerous cells highlighted with quantum dots. These goggles could also be used to develop diagnostic tests and therapies for other conditions.

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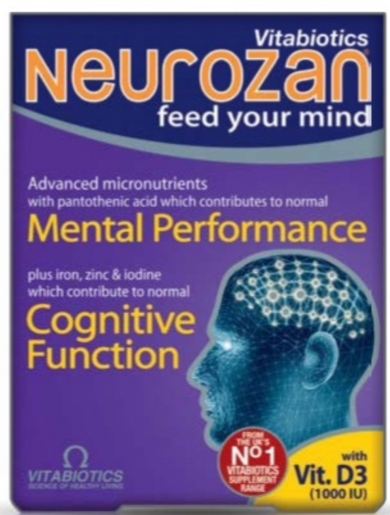
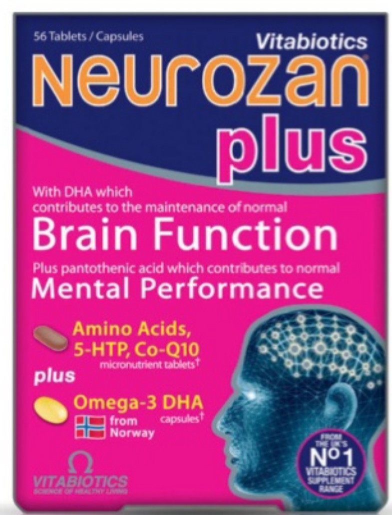
Neurozan® Plus dual pack provides even greater nutritional support with high purity Omega-3 from Norway. DHA helps to maintain normal **brain function**.

So if you're looking for a supplement that's different, keep *Neurozan®* in mind.



ORIGINAL



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† Professor Beckett is not cited in the capacity of a health professional, but as a product inventor and former Chairman of Vitabiotics. *(IRI value data. 52 w/e 2 Nov 13).

VITABIOTICS
SCIENCE OF HEALTHY LIVING

Niels Bohr

Studying atoms and quantum mechanics, Bohr knew small things can make a big difference

The structure of atoms is an integral part of the study of physics. The discovery of the way electrons move around a nucleus has widened our knowledge of physical matter significantly, and for a large part of this we have Danish physicist Niels Bohr to thank. Born in Copenhagen in 1885, Bohr's father Christian was a well-known physiologist. This early grounding in science helped Niels go on to receive a master's degree and a doctorate from the University of Copenhagen.

After graduating he worked in his father's laboratory, where his ideas of atomic structure and radiation were first outlined after studying Max Planck's quantum theory.

In 1911, Bohr went to study in England – first in Cambridge and then Manchester. His teacher was Professor Ernest Rutherford who was known by many as the 'father of nuclear physics'. The two enjoyed a good relationship and it was at this time that Bohr developed his ideas on atomic structure and his groundbreaking atomic model. His theory built upon Rutherford's initial model and incorporated aspects of Planck's quantum theory. This model describes a positively charged nucleus surrounded by negative electrons that travel in circular orbits at a set distance determined by energy levels.

The success of his theory meant that, by 1916, Bohr was back in Copenhagen as a professor of theoretical physics at his old university. Further success followed as he was awarded a 1922 Nobel Prize for his investigation into the structure of atoms. He would work on many other ideas over his career, including the liquid droplet theory, the hydrogen spectrum, electromagnetic theory, absorption of alpha rays and the transmutations of atomic nuclei. The liquid droplet theory was particularly revolutionary at the time, as it formed the basis for how we now split uranium.

When WWII broke out, Bohr joined the Atomic Energy Project, working with the US on a nuclear bomb in the Manhattan Project. After contributing to these projects, Bohr wrote an open letter to the UN after the war, encouraging a more peaceful application of atomic physics and this was a precursor to him organising the Atoms for Peace Conference in 1955.

In later life, he helped establish research centre CERN in Switzerland and the Nordic Institute for Atomic Physics. He also advocated using nuclear power in his home country of Denmark before his death in 1962.

A life's work

We highlight some of the milestones over this atomic scientist's career

1885
Niels is born on 7 October in Copenhagen to Ellen and Christian Bohr.

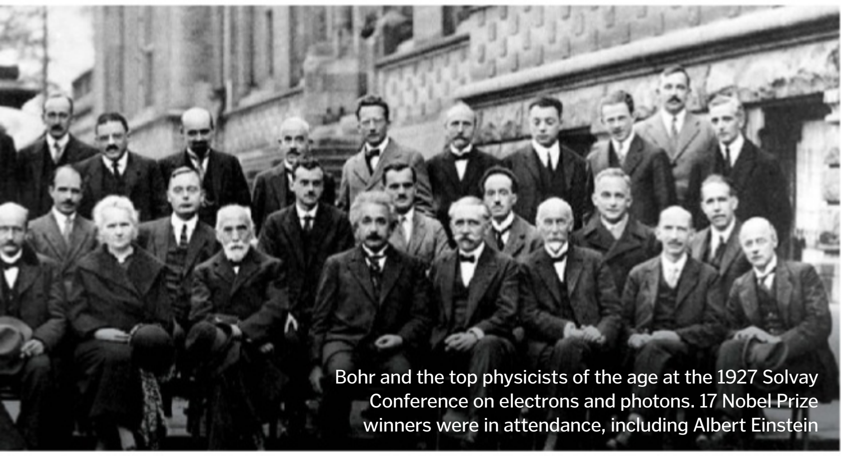
1911
Obtains doctorate and works under physicist JJ Thomson in Cambridge, England.

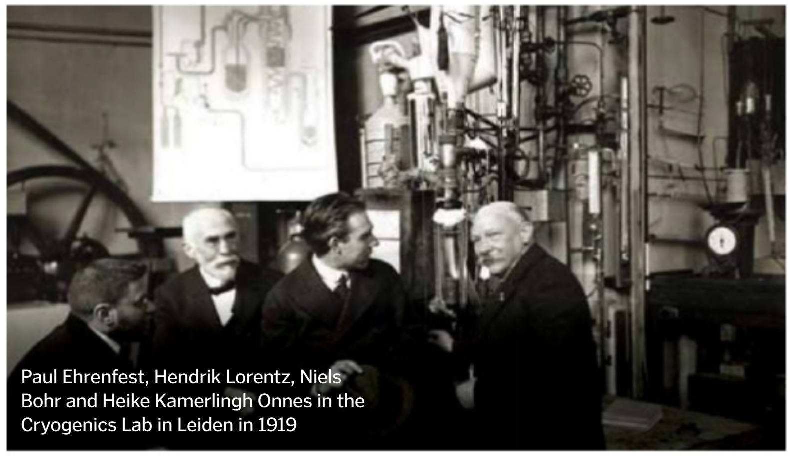
1912
Working under Professor Ernest Rutherford, Bohr looks to reassess atomic structure by applying quantum theory.

1916
Appointed professor of theoretical physics at the University of Copenhagen.

1922
Awarded the Nobel Prize in Physics for 'services in the investigation of the structure of atoms and of the radiation emanating from them'.

1927
Attends Solvay Conference on electrons and photons, and meets Einstein for the first time.


Bohr and the top physicists of the age at the 1927 Solvay Conference on electrons and photons. 17 Nobel Prize winners were in attendance, including Albert Einstein

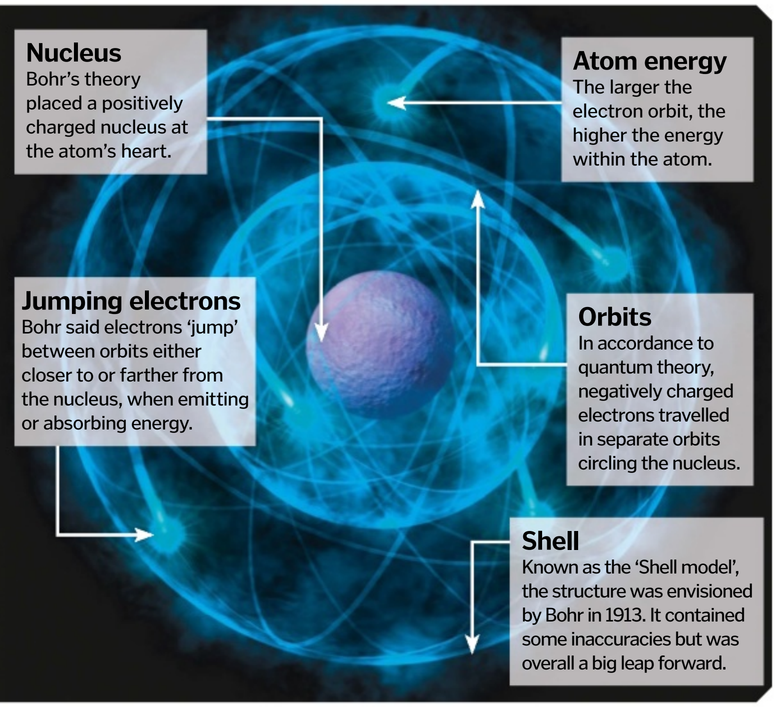

Paul Ehrenfest, Hendrik Lorentz, Niels Bohr and Heike Kamerlingh Onnes in the Cryogenics Lab in Leiden in 1919

The big idea

Niels Bohr's biggest contribution to the world of physics came in the form of his ideas on atomic structure and, in particular, his groundbreaking new atomic model. This model was the first to show that electrons orbit the nucleus at specific distances, which are dictated by laws of quantum physics.

Bohr's new theory rendered previous atomic theories obsolete, such as JJ Thomson's 'plum pudding' model of 1904 and Lord Kelvin's earlier vortex model.

Although it has been considerably improved upon and modified since 1913, the original Bohr model is still frequently used today as a simple explanation of atomic structure, without the complex quantum calculations of the modern model, so Niels Bohr will continue to teach us about physics well into the 21st century.



Top 5 facts: Niels Bohr

1 Sporty scientist
As well as his achievements in physics, Bohr was a keen footballer and played in goal for one of the biggest teams in Denmark – Akademisk Boldklub (AB).

2 Great escape
Denmark was occupied by the Third Reich during WWII so Bohr fled to Sweden and then the UK and the US to help with the atomic energy project.

3 Well travelled
In 1937 Bohr, his wife and their son Hans went on a world tour. They travelled to the USA, Japan, China and the USSR giving speeches and holding meetings all over the globe.

4 Brother Harald
Niels' brother was a mathematician who worked on the Dirichlet series and applied analysis to the theory of numbers. He was a national team footballer, gaining an Olympic silver medal in 1908.

5 Lasting legacy
The Danish-found asteroid 3948 Bohr is named after him, as is a lunar crater and the chemical element bohrium.

Atomic models over time

<500 BCE
Four elements of earth, air, fire and water, with differing colours/odours.

500-400 BCE
Atoms are considered indivisible and made of the same substance.

1867 CE
Lord Kelvin's vortex model describes a twisted knot or vortex shape.

1904
JJ Thomson's 'plum pudding' has electrons embedded in a positive sphere.

Present
Modern atomic structure consists of 'clouds' of charge containing electrons.

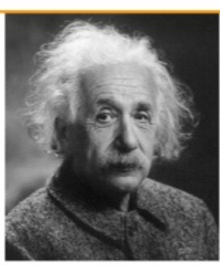
In their footsteps…

Werner Heisenberg

Having worked with Bohr in Copenhagen, Heisenberg advanced his ides of atomic structure. His uncertainty principle countered Bohr's theory that electrons travel in neat orbits. Heisenberg's notion still forms some of the current understanding of atoms. He won the Nobel Prize in Physics in 1932 after devising a way to use matrices to formulate quantum mechanics.

Aage Bohr

A long-term assistant to his father, Aage Bohr accompanied Niels Bohr on the Manhattan Project and succeeded him as director of the University of Copenhagen. He shared the Nobel Prize in Physics in 1975 with his work on determining asymmetrical shapes of atomic nuclei. The younger Bohr's discoveries were essential in the development of nuclear fusion.



1943
Leaves Denmark in WWII and persuades Sweden to provide asylum for Jews. Later moves to the UK and then the USA.

1943-1945
Contributes to both the Atomic Energy and Manhattan projects.

1950
Writes open letter to the UN, outlining political problems with the development of nuclear weapons.

1955
Sets up the Atoms for Peace Conference, winning the first US Atoms for Peace Award two years later.

1962
Dies of heart failure in his home city of Copenhagen on 18 November.

1965
The University of Copenhagen's Institute for Theoretical Physics is officially renamed the Niels Bohr Institute.

Jerusalem under siege

From Roman battles to WWI, this city has seen more than its fair share of conflict

In its long history, the city of Jerusalem has been besieged over 20 times. One of the oldest cities in the world, it has been the scene of Roman civil wars, holy crusades and even a world war.

The first siege of the Common Era was when the city was under Roman rule in 70 CE. Started by the Great Jewish Revolt in 66 CE, the Jews were incensed when a Roman official stole from the synagogue. Jews rose up against their oppressors' rule and established Jerusalem as the centre of rebellion. Subsequently, Emperor Vespasian ordered a force led by General Titus to retake the city. Battering rams, catapults and siege towers were used to destroy the walls and sacred relics from the city's temple were stolen. The Arch of Titus in Rome was built to commemorate the victory.

Perhaps the most famous of all Jerusalem's conflicts, though, were the Crusades. In the First Crusade of 1099, a Christian army with 12,000 infantry and 1,500 cavalry took the city. Siege towers and scaling ladders were used to overwhelm the defences of one of the best-defended metropolises of the age.

This victory led to a counterattack in 1187 from Saladin of the Ayyubid Dynasty. The city, still under Christian rule, was defended by Balian of Ibelin. At first, Saladin negotiated for a peaceful surrender but after it was rejected he began besieging Jerusalem.

He focused his attacks on the Tower of David and the Damascus Gate. The assault was repelled so the attention was turned to the Mount of Olives, which had no gate. This proved to be a tactical masterclass and, just as the Christian stronghold was about to fall, Balian offered a negotiated surrender to which Saladin eventually agreed. The later Third Crusade led by Richard the Lionheart and Philip II in 1189 aimed to reclaim the city, but ultimately failed.

The next major siege was centuries later in 1917 during World War I. A battle between the British and the Ottoman Empire, the city fell into Allied hands after several days of fighting. The city remained under British rule until 1948, when the Arab-Israeli War divided Jerusalem between Israel and Jordan, leading to decades of internal conflict. Today, it is the capital of two sovereign states: Israel and Palestine.

The battle for Jerusalem

Discover how the city was besieged on the First Crusade in 1099

Why is Jerusalem so sought after?

Jerusalem has been regarded as a city of religious significance for Jews, Christians and Muslims for over 2,000 years. For Crusaders, the city needed to be recaptured from Muslim rule, as it was essential to pilgrimages. In Judaism, Jerusalem is considered holy and is often known as Zion. Jews believe the city was designed for them by God. For Islam, the city contains one of the holiest mosques after that in Mecca and is known as Al-Quds. Jerusalem was also geographically important for different empires to get a foothold on the Middle East for military campaigns and trade.

Road to Jerusalem

Jerusalem was the main target for the First Crusade – here's how the conquest unfolded

Nov 1095
Christian armies from the West, encouraged by Pope Urban II, decide to recapture the Holy Land from the Muslims.

Dec 1096
Western forces arrive in the Byzantine capital of Constantinople to begin the war.

Jun 1097
The Anatolian city of Nicaea is captured, followed by an eight-month siege of Antioch (right).

5 TOP FACTS
FAMOUS SIEGES

Gibraltar
1 The Great Siege of Gibraltar was a French and Spanish attempt to take over the British stronghold. Lasting over three years, the British held out despite navy blockades.

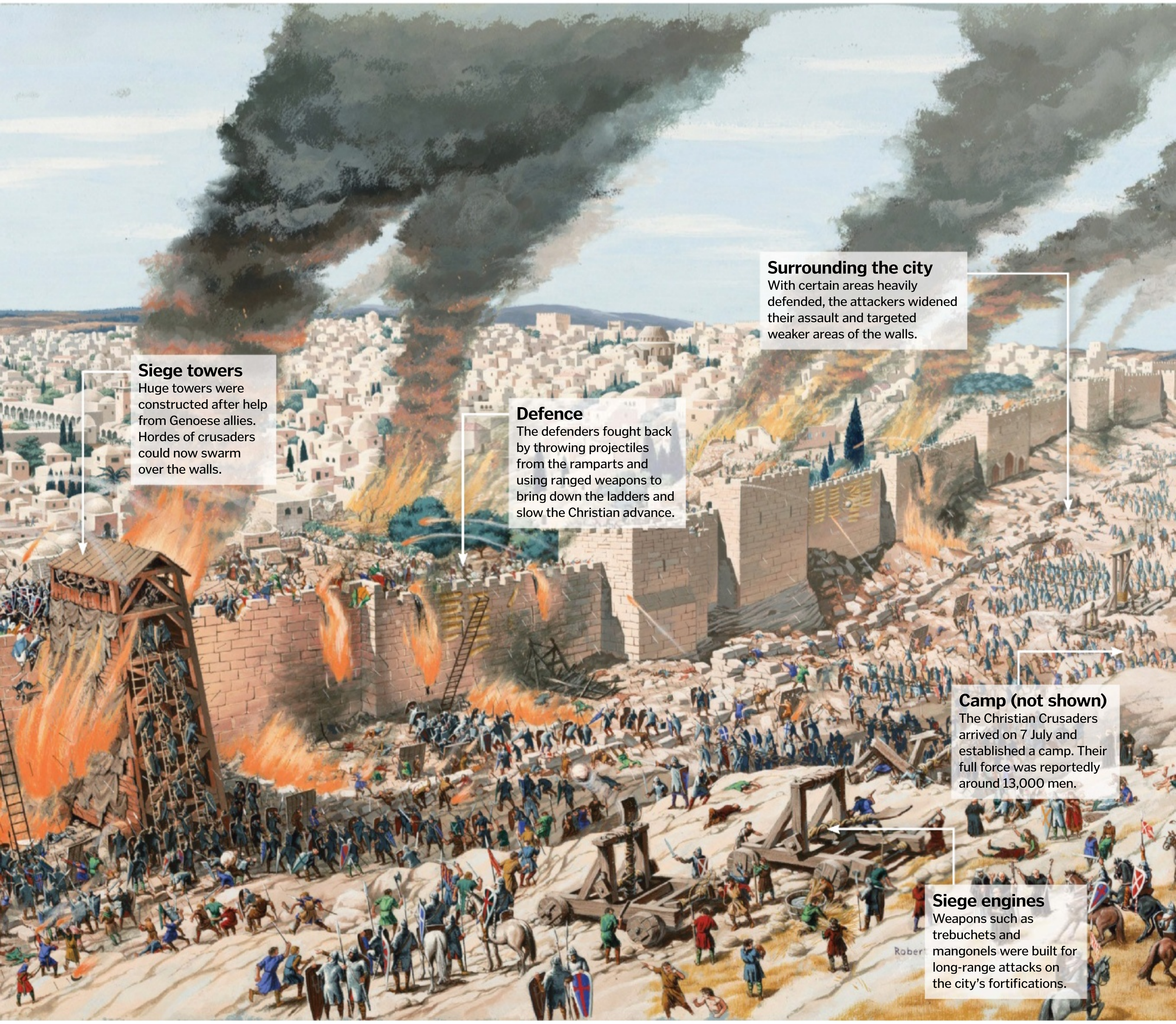
The Alamo
2 Fought during the Texas War of Independence in 1836, the Alamo is renowned for the bravery of 200 Texans who held out over a 13-day siege against 6,000 Mexicans.

Candia
3 Lasting for two decades, the Siege of Candia is the longest in history. 60,000 Ottomans attacked the Venetian city in Crete in 1648 and it eventually succumbed in 1669.

Constantinople
4 In 1453, just 10,000 men stood against 100,000 Ottomans. Cannons and warships led to not just the city's demise but also the fall of the Byzantine Empire.

Stalingrad
5 In 1942, Soviet city Stalingrad was surrounded by German forces. Fierce street-to-street fighting ensued, eventually resulting in a Russian victory and a turn of the tide in WWII.

DID YOU KNOW? *2005's Hollywood blockbuster film Kingdom Of Heaven is based on the 1187 Siege of Jerusalem*



Jul 1097
The first big skirmish of the campaign at Dorylaeum results in heavy losses but a Christian win.

Dec 1097
The Muslims, led by Duqaq and Ridwan, strike back in two battles at Harenc but are repelled.

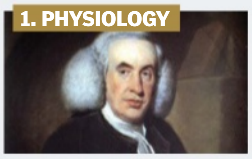
Jun 1098
The Battle of the Orontes sees a 75,000-strong Islamic army, low on morale, defeated by 15,000 Christians.

Jun 1099
The Siege of Jerusalem begins and the Crusaders are victorious by July (right).

Aug 1099
At the Battle of Ascalon, an Egyptian force of 50,000 is defeated by the Crusaders. With Jerusalem still under Christian control, the First Crusade ends.

HEAD 2 HEAD
18TH-CENTURY MEDICS

1. PHYSIOLOGY

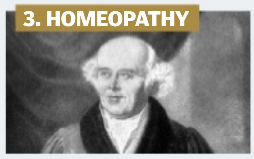


William Cullen
A professor at the Edinburgh Medical School, Cullen's teachings inspired physicians like William Withering, Joseph Black and Benjamin Rush.

2. VACCINATIONS

Edward Jenner
Jenner was the first to understand vaccination and proved that an injection of mild cowpox would make you immune to more deadly smallpox.

3. HOMEOPATHY



Samuel Hahnemann
The original founder of homeopathy, he was one of the first to describe the use of highly diluted drugs to allow the body to heal itself.

DID YOU KNOW? *The term 'apothecary' originates from the Latin 'apotheca', which is where spices and herbs were stored*

Apothecary secrets

What are the origins of the pharmaceutical industry?

It's thought the first apothecary – which can mean both pharmacy or pharmacist – emerged in Ancient Babylon and was introduced to the West by Galen, a Roman doctor. It originally revolved around the preservation of food, but its focus shifted to the relationship of drugs and medicines with living systems and the process of recording symptoms for the cure and prevention of disease.

The preparation and selling of medicines was handled by an apothecary after the Society of Apothecaries was established in London in 1617. By the 19th century, their role had evolved. The Apothecaries Act in 1815 meant that chemists now had to have formal qualifications and provide medical care and surgery, while new chemist shops would look after the retail side. The practice evolved into pharmacology as new substances were developed such as morphine, strychnine, atropine and quinine. Morphine, for example, was isolated in 1805 by Friedrich Setürner who stirred and heated opium in methanol.

Apothecaries remained prominent throughout the 20th century, with about 100 apothecaries still in the USA during the 1960s. The age of apothecaries all but came to an end in the 1980s as large chain drug stores superseded them.

A replica of an 18th-century apothecary shop in Mexico

Apothecary treatments

1 Artificial leech

Rather than using real leeches for bloodletting, a man-made alternative was created by Carl Baunscheidt in the mid-19th century. It was a pen-like device with a group of tiny needles on the end.

2 Vesiculation

Used to combat madness and hypochondria, this involved intentionally raising blisters on the skin.

3 Clysters

A medicine injected to help nutrition and cleanse the bowels. Along with vomiting and bloodletting this was seen as a way of 'purging' the body of bad elements.

4 Chamomile

A flower that had sedating and anti-inflammatory effects, it was prescribed for colds and infections and was one of many plants used in medicine.

Compass of the oceans

The device mariners once used to navigate the seven seas

The age of discovery owes a lot to the mariner compass. The journeys of pioneering explorers such as Columbus and Vasco de Gama would never have been undertaken if it wasn't for the instrument's ability to help navigate Earth's vast oceans. Like so many instruments of its time, it was originally invented in China. The mariner's compass, or dry compass, was first introduced to Europe around 1300.

Its key components were the gimbal, which allowed the compass to rotate on its axis, a compass card that marked the directions on its face and a lubber line that was used for reference. This was then all held together in a brass frame and wooden box for protection.

Later, in 1745, Dr Gowin Knight designed a needle of magnetised steel that lasted longer and worked with much more precision than the previous version. This was essential to lengthy ocean expeditions, as the needles would not need to be replaced or remagnetised. An upgrade of this system was devised by silversmith Francis Crow in 1813; the new 'liquid compass' had the needle floating on a mix of alcohol and water, again improving on the mechanism's accuracy.

Learn more

To learn more about mariner compasses, dynamos, magnets and much more, the Energy Show will be touring England and Wales until July 2014. Run by the London Science Museum, it's a must-see for science fans – get more details here: **bit.ly/QVNRfh**.

"Due to the rods being raised too far and too quickly, a dangerous power surge occurred"

What went wrong at Chernobyl

Learn how a runaway reaction led to a nuclear disaster…

On 25 April 1986, engineers at the nuclear plant at Chernobyl began a test that would lead to the worst nuclear disaster in history. The power plant, located some 130 kilometres (80 miles) north of Kiev, Ukraine, was completed in 1983. Three years later, engineers ran an experiment to see how long the turbines could continue producing energy in the event of a power cut.

The first fatal error made by the technicians that day was to turn off the safety systems. They would have affected the experiment, which involved running the plant at low power, but this action prevented workers realising the dire situation they were soon to put themselves in.

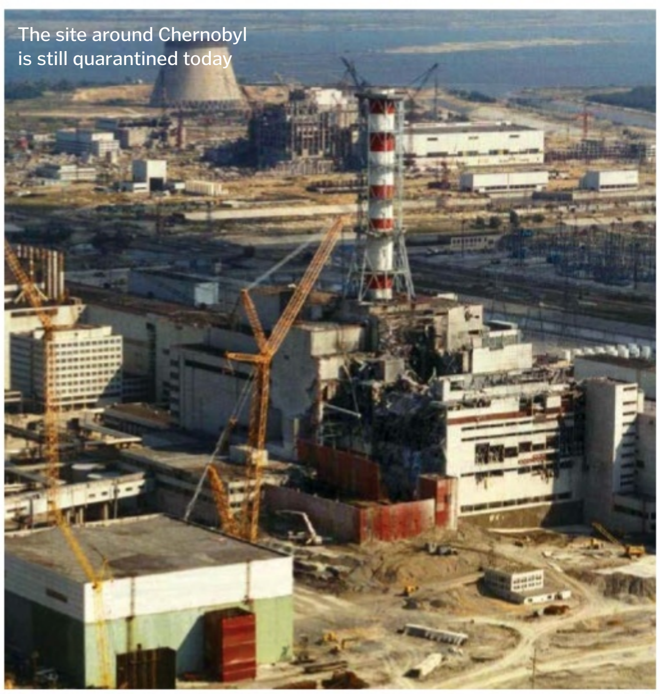
The process of creating nuclear fission is regulated by control rods, which, when inserted into the reactor core, absorb neutrons and slow production. The idea was to lower lots of these rods to reduce the power output and see what happened. Unfortunately, too many were lowered and the output dropped at too high a rate. Rods were then raised again to increase output, returning to about 12 per cent.

However, due to the rods being raised too far and too quickly, a dangerous power surge occurred and the reactor overheated, the water cooling system unable to cope with the sudden demand, turned to steam.

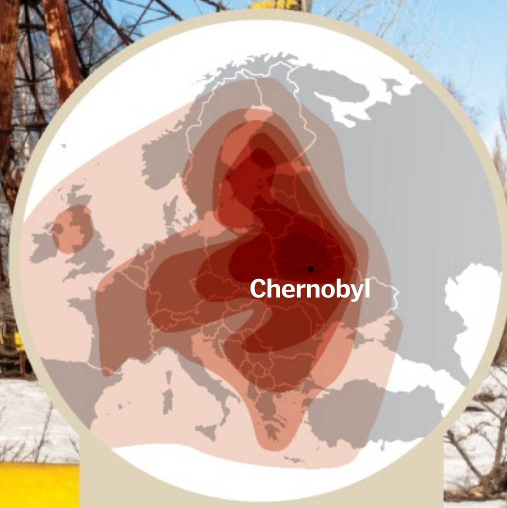
The emergency button was pressed and the rods began to lower but this led to even more rapid reactions in the core.

In the early hours of 26 April, the reactor's roof was blown off and radioactive material began to escape into the atmosphere.

The fire took nine days to extinguish and the radioactive material had far-reaching health and political consequences.



The site around Chernobyl is still quarantined today



Nuclear fallout

The explosion and meltdown was shocking enough, but worse was still to come in the form of radiation spread and health issues for much of Europe.

31 people died immediately after the event with 28 of those deaths a direct result of radiation poisoning inside and around the power plant site.

The worst of the fallout centred around Chernobyl, but increased levels of radiation were detected in areas as far away as the UK, Portugal and Sweden.

Thyroid cancer, caused by the inhalation of contaminated air, has increased tenfold in adolescents in Belarus since 1986 with cases in adults also rising. Cases in children up to the age of 14 also increased, but that number has since reduced due to many of that age group being born after the event.

The impact of the contaminated air has also affected animals, crops and water supplies and the effects are still widely felt to this day. Radiation levels around Chernobyl will remain far higher than average for many millennia.

5 TOP FACTS
CHERNOBYL TRIVIA

Zircaloy rods
1 The control rods were made of neutron absorbing elements, encased in a tube of zircaloy. This was used as it is capable of resisting corrosion by radiation.

Power output
2 The fuel used in Chernobyl was two per cent uranium-235, a frequently-used fission material, and each reactor produced around 1,000MW of energy.

Big bang
3 The buildup of pressure and temperatures of over 2,000°C (3,632°F) caused an explosion that reportedly rose 1,000 metres (3,280 feet) into the air.

Fighting the fire
4 Helicopters doused the flames in boron to slow the nuclear reactions, lead to form a barrier from the radiation and sand to dampen the flames.

Concrete cover-up
5 A reinforced concrete case was constructed around the plant to block radiation. A replacement is currently being built and should be ready in 2015.

DID YOU KNOW? *At least 30 of the 50 rods needed to be inserted to be safe; when the plant exploded only six were inserted*

Countdown to disaster

Find out how history's worst nuclear accident played out

1 Safety switches
The safety switches were intentionally turned off to allow the experiment to run without intervention.

2 Rods dropped
Control rods were lowered to reduce power output, but the power reduced too much too quickly.

3 Rods raised
In order to get the plant working again, the rods were raised causing a rapid increase in production.

4 Water heating
The all-important cooling water began to overheat, turning to steam and failing to cool the reactor.

5 Emergency
Pressing the emergency button lowered the rods again, but they displaced the remaining water.

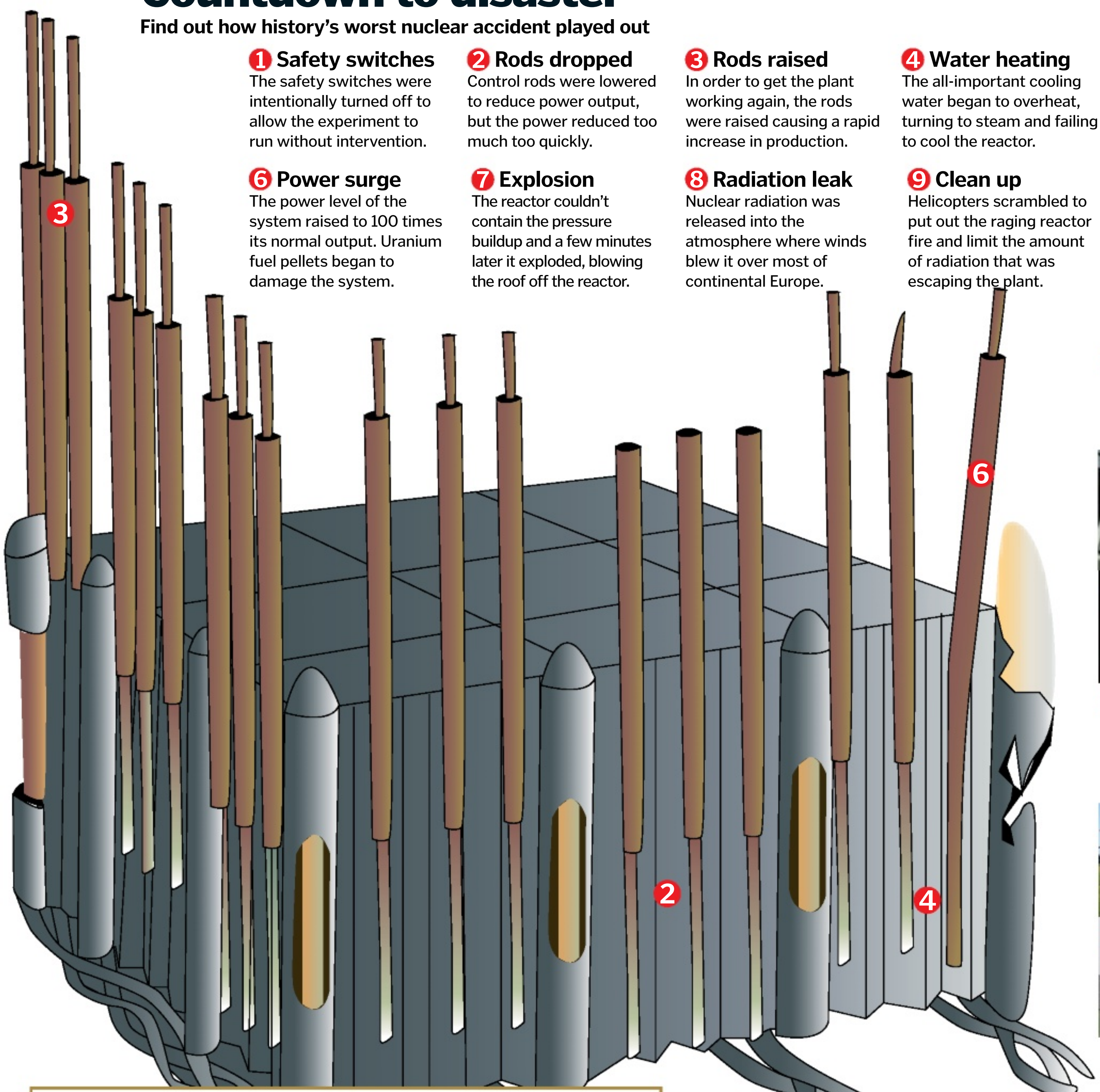
6 Power surge
The power level of the system raised to 100 times its normal output. Uranium fuel pellets began to damage the system.

7 Explosion
The reactor couldn't contain the pressure buildup and a few minutes later it exploded, blowing the roof off the reactor.

8 Radiation leak
Nuclear radiation was released into the atmosphere where winds blew it over most of continental Europe.

9 Clean up
Helicopters scrambled to put out the raging reactor fire and limit the amount of radiation that was escaping the plant.

10 Sarcophagus
A concrete shell was hastily constructed and placed over the nuclear plant to limit the release of radiation from Chernobyl.



How it toppled the USSR

The leader of the Soviet Union at the time of the Chernobyl disaster, Mikhail Gorbachev, has claimed that the incident was a key factor in the demise of the USSR.

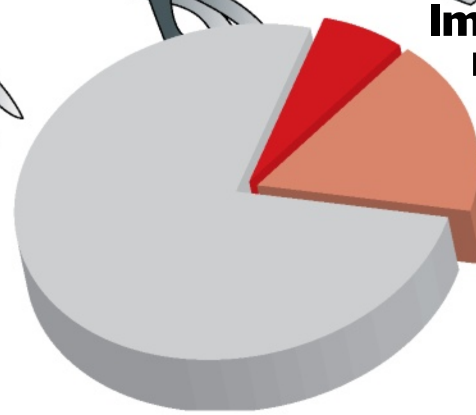
The government's response to the disaster was to try and cover it up as much as possible, with barely any official announcement of it and no warning to residents in the surrounding area as to the dangers of radioactive poisoning. It took a radioactive cloud that passed over Sweden to bring the event to the world's attention.

Furious at the lack of information and protection they had received, especially as Gorbachev had promised a new era of political clarity and honesty, citizens railed against the political system.

The general public lost faith in the government and the government in turn lost control of the general public. Five years later, the Soviet Union was dissolved with Gorbachev quoted as saying, "The nuclear meltdown at Chernobyl […] was perhaps the real cause of the collapse of the Soviet Union."

Impact of the meltdown

How many were directly affected by the disaster?



55,000
6.4% died from radiation

150,000
17.4% were left disabled

655,000
76.2% underwent medical supervision

BRAIN DUMP

Because enquiring minds need to know...

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MEET THE EXPERTS

Who's answering your questions this month?

Luis Villazon

Luis has a degree in zoology and another in real-time computing. He's been writing about science and technology since before the web. His science-fiction novel, *A Jar Of Wasps*, is published by Anarchy Books.

Dave Roos

A freelance writer based in the United States, Dave has written about every conceivable topic, from the history of baseball to the expansion of the universe. He has an insatiable appetite for science and technology.

Alexandra Cheung

Having earned degrees from the University of Nottingham as well as Imperial College, Alex has worked at many a prestigious institution around the world, including CERN, London's Science Museum and the Institute of Physics.

Rik Sargent

Rik is a science communicator who has a background in physics and public engagement, having worked at the Institute of Physics. Pastimes include experimenting with sound, baking cakes as well as the complex science of brewing coffee.

Giles Sparrow

Giles studied Astronomy at UCL and Science Communication at Imperial College, before embarking on a career in space writing. His latest book, published by Quercus, is *The Universe: In 100 Key Discoveries*.

Shark-proof cages have enabled us to study these majestic creatures in closer proximity than ever before

When did we first cage-dive with sharks?

Zara

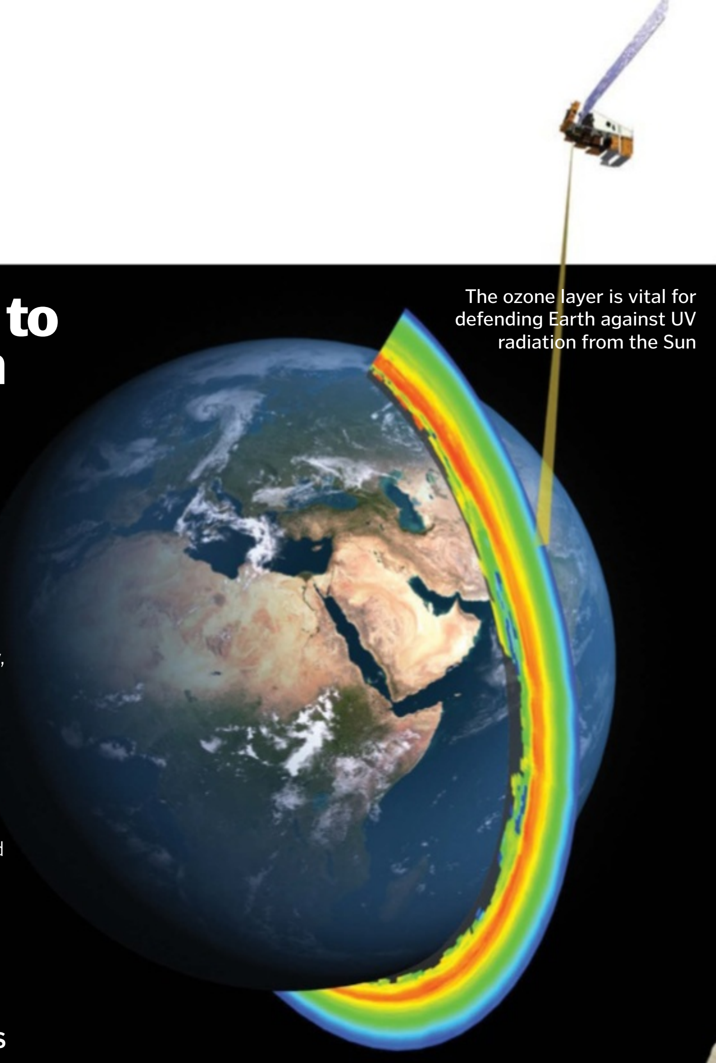
■ The first purposely shark-proof cage was built in the mid-1960s by Rodney Fox, an Australian who had survived a violent shark attack just a few years earlier. Much like today's cages, it allowed divers to safely approach sharks, enclosed in a tough metal cage suspended from the back of a boat. After his accident, Fox grew passionate about studying these supreme predators in more detail than had been done previously and used the cage to observe and film them up close, providing footage for documentaries and films, including *Jaws*. In 1976, Fox led the first cage-diving expeditions for amateur divers. **AC**

Why do our tastes change as we get older?

Debra St-Claire

As we age, several factors can cause a shift in our food preferences. Children have an innate preference for sweet food and drinks, disliking strong and particularly bitter tastes. As they grow older this changes, with many people growing to enjoy bitter flavours such as coffee. Once we hit middle age, the number of taste buds on our tongue gradually diminishes and our sense of smell declines, making food taste bland. Experience and culture also affect our perception, and a bad experience with a certain food or drink can also change our tastes. **AC**

Is there any way to mend the hole in the ozone layer?


The ozone layer is vital for defending Earth against UV radiation from the Sun

Cathy Halfpenny

The ozone layer is a region of oxygen molecules with an unusual tri-atomic structure (O_3), roughly 20-50 kilometres (12-31 miles) above the surface. Here, ozone molecules are constantly being created and destroyed by interactions of normal oxygen (O_2) with ultraviolet light from the Sun, shielding Earth's surface from this dangerous radiation. Normally, the amount of ozone being created and destroyed is perfectly balanced, but in the 20th century, industrial chemicals added to the depletion of ozone and the layer grew thin in places. In theory, it might be possible to 'heal' the ozone layer by artificially pumping huge amounts of ozone or normal oxygen into the upper atmosphere, but such a project would be impossibly expensive and almost certainly counterproductive once the energy and pollution involved were taken into account. Happily, however, the layer is capable of regenerating itself over time, and since bans and restrictions on ozone-depleting chemicals were introduced in the past few decades, the recovery process does seem to have begun. **GS**

COOL FACTS

The highest bridge is nearly 500m up

The title of world's highest bridge is held by the Siduhe River Bridge, located in central China. Spanning a deep valley, its height from valley floor to deck is 496m (1,627ft).

Who was El Cid?

Lloyd Gallagher

El Cid was a legendary military leader in medieval 11th-century Spain. His real name was Rodrigo Díaz de Vivar, son of minor nobility, an educated scholar and a soldier in the court of Prince Sancho.

He catapulted to fame as a 22-year-old warrior when he defeated a decorated knight in one-on-one combat, earning him the nickname 'El Campeador', or 'The Champion'. El Cid was a cunning and beloved general, leading both Christian and Muslim armies for princes and kings across northern Spain before carving out his own independent state near Valencia in the south. The name El Cid is derived from 'sayyid' – Arabic for 'lord'. **DR**

Has anyone ever broken into Fort Knox?

Adrian Higginson

Not only has there never been a successful robbery of Fort Knox, but no one has even attempted it since the vault opened in 1935. There are no visitors allowed. Even if you could somehow get past the military checkpoints, the armed garrisons and the hundreds of tons of concrete, granite and steel encasing the gold vault, you would be in for a heavy surprise. There are 4.2 million kilograms (9.2 million pounds) of gold currently stored at Fort Knox. That's the equivalent of about 338,710 gold bars, each weighing 12.4 kilograms (27.4 pounds). In short, you would need an army and a caravan of armoured trucks to steal the loot. **DR**

Can insects be trained like other animals?

Hiroko Maki

Although they may not rival dogs or other mammals, most insects do have the ability to learn and therefore be trained to some extent. Animals are trained through classical conditioning, where they learn to associate two events – for example, performing a trick and receiving a reward. Researchers have used this technique to train wasps to detect scents by repeatedly exposing them to a smell and then feeding them sugar water. After a few minutes' training, the wasps respond to the smell by crowding around it. However, insects' limited intelligence means that they have a much smaller capacity for learning than most pets. **AC**

What do footballs and gum have in common? Find out on page 82


Human teleportation remains a distant dream, with its immense technological challenges

Do you think we will ever be able to teleport people?

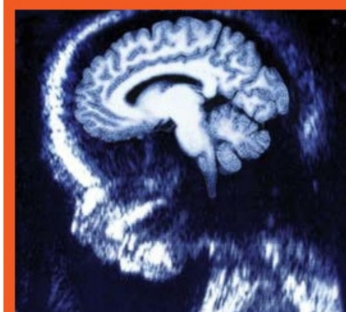
Flavia Costa

■ 'Never' is a strong word, but it's highly unlikely that teleportation of a human being á la *Star Trek* will ever be possible, given our current understanding of quantum physics and the known laws of the universe. To teleport a person, you would have to scan the exact location and physical properties of each of the 7 x 10^{27} atoms in the human body. The first obstacle is the uncertainty principle, which states that the more accurately you measure one property of a quantum particle, the less accurately you can measure others. We could know an atom's location, for example, but not its mass. Even if you could work around the uncertainty principle, you would need to scan and send an unimaginable amount of data – 10,000 times the current storage capacity of all of the world's computers – quickly enough to reconstruct living tissue. Plus, true teleportation requires the destruction of the original. Any volunteers? **DR**

COOL FACTS

Babies are brainier than they seem

At birth, your brain contains 100 billion nerve cells called neurons. Although there is some evidence that we continually grow new neurons, scientists agree that we lose roughly 10,000 each day.

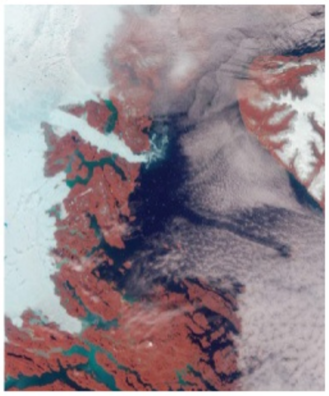


Chewing gum and footballs are made of the same thing

The main ingredient in chewing gum is synthetic polyisobutylene rubber – the same rubber used for footballs, gas masks and tire inner tubes. This is combined with softeners such as vegetable oil and paraffin wax.

Petrol is not the most expensive liquid

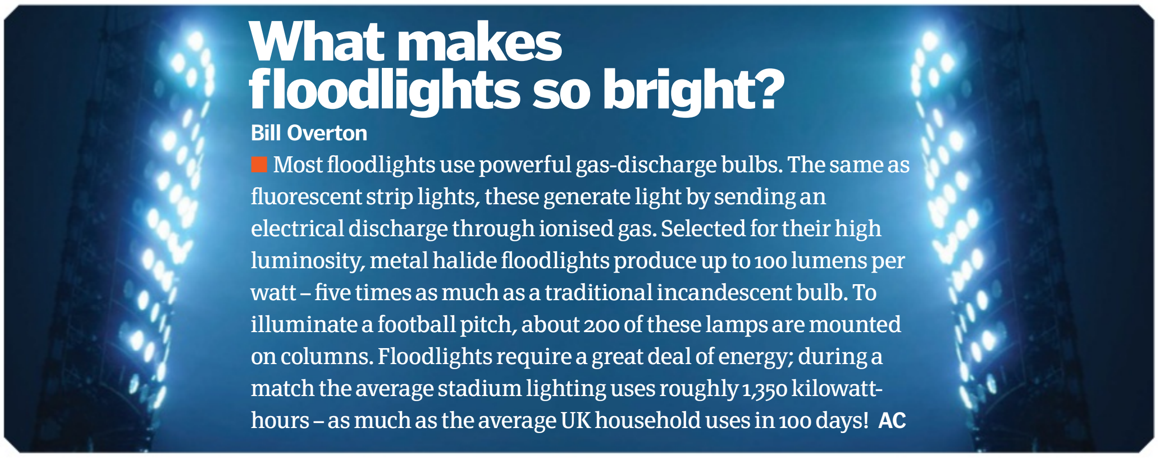
Petrol is relatively cheap compared to some of the most expensive liquids such as insulin, perfumes and venoms. Scorpion venom – which has medical applications – is particularly costly, with some strains valued at nearly £100 ($170) per milligram (0.015 grains).



How fast do glaciers move?

Lee Delaney

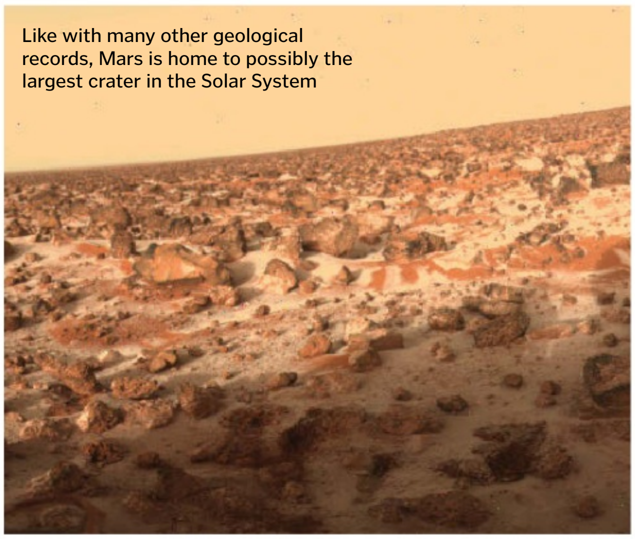
The speed at which a glacier flows depends on its mass, the depth and slope of the underlying rock bed and friction. The fastest glacier in the world is the Jakobshavn Glacier in Greenland, clocked in moving at a blazing 46 metres (151 feet) per day – or 17 kilometres (10.6 miles) per year – in 2012. The average flow rate for glaciers worldwide is far more 'glacial' at less than 500 metres (547 yards) per year. Climate change is contributing to temperature rises and faster glacier speeds at the poles. Ice loss from Greenland alone is believed to have contributed to a quarter of the total sea-level rise over the past two decades. **DR**



What makes floodlights so bright?

Bill Overton

Most floodlights use powerful gas-discharge bulbs. The same as fluorescent strip lights, these generate light by sending an electrical discharge through ionised gas. Selected for their high luminosity, metal halide floodlights produce up to 100 lumens per watt – five times as much as a traditional incandescent bulb. To illuminate a football pitch, about 200 of these lamps are mounted on columns. Floodlights require a great deal of energy; during a match the average stadium lighting uses roughly 1,350 kilowatt-hours – as much as the average UK household uses in 100 days! **AC**



Like with many other geological records, Mars is home to possibly the largest crater in the Solar System

What's the Solar System's biggest impact crater?

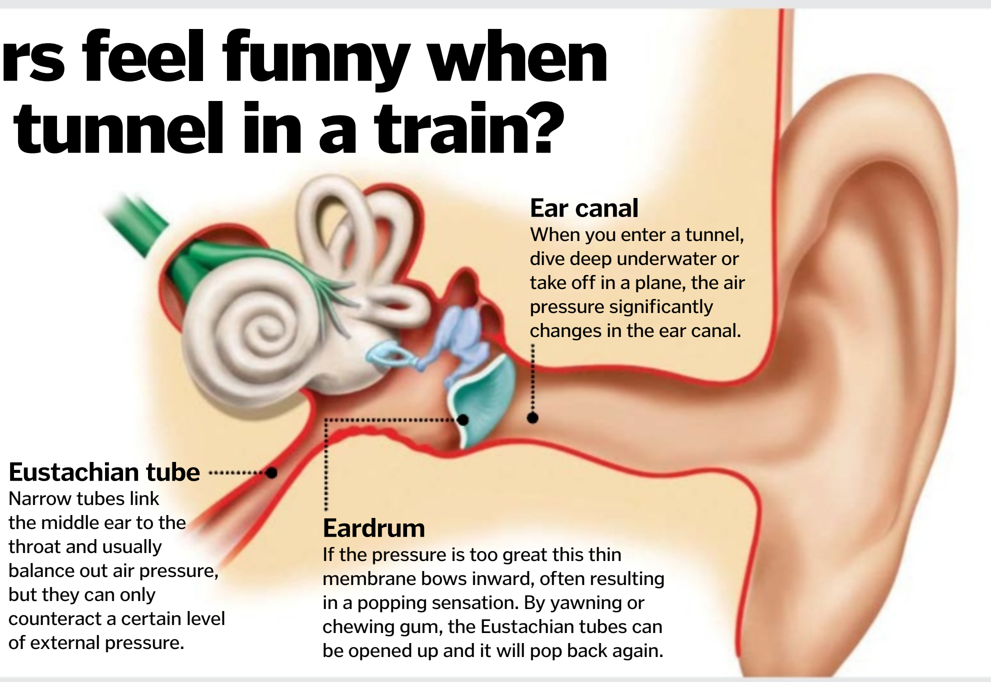
Archie Mulligan

The largest obviously visible crater, at 2,300 kilometres (1,429 miles) in diameter, is the Hellas Basin on Mars. That said, the South Pole-Aitken Basin (largely on the far side of the Moon, filled with countless other craters) is over 2,500 kilometres (1,553 miles) across. However, Mars has at least one concealed crater even bigger than that – the low-lying plain of the Utopia Planitia region is thought to have been an impact crater some 3,300 kilometres (2,051 miles) across, and scientists are still debating whether the entire Martian north polar region is a massive impact basin over 10,600 kilometres (6,587 miles) wide. **GS**

Why do my ears feel funny when I go through a tunnel in a train?

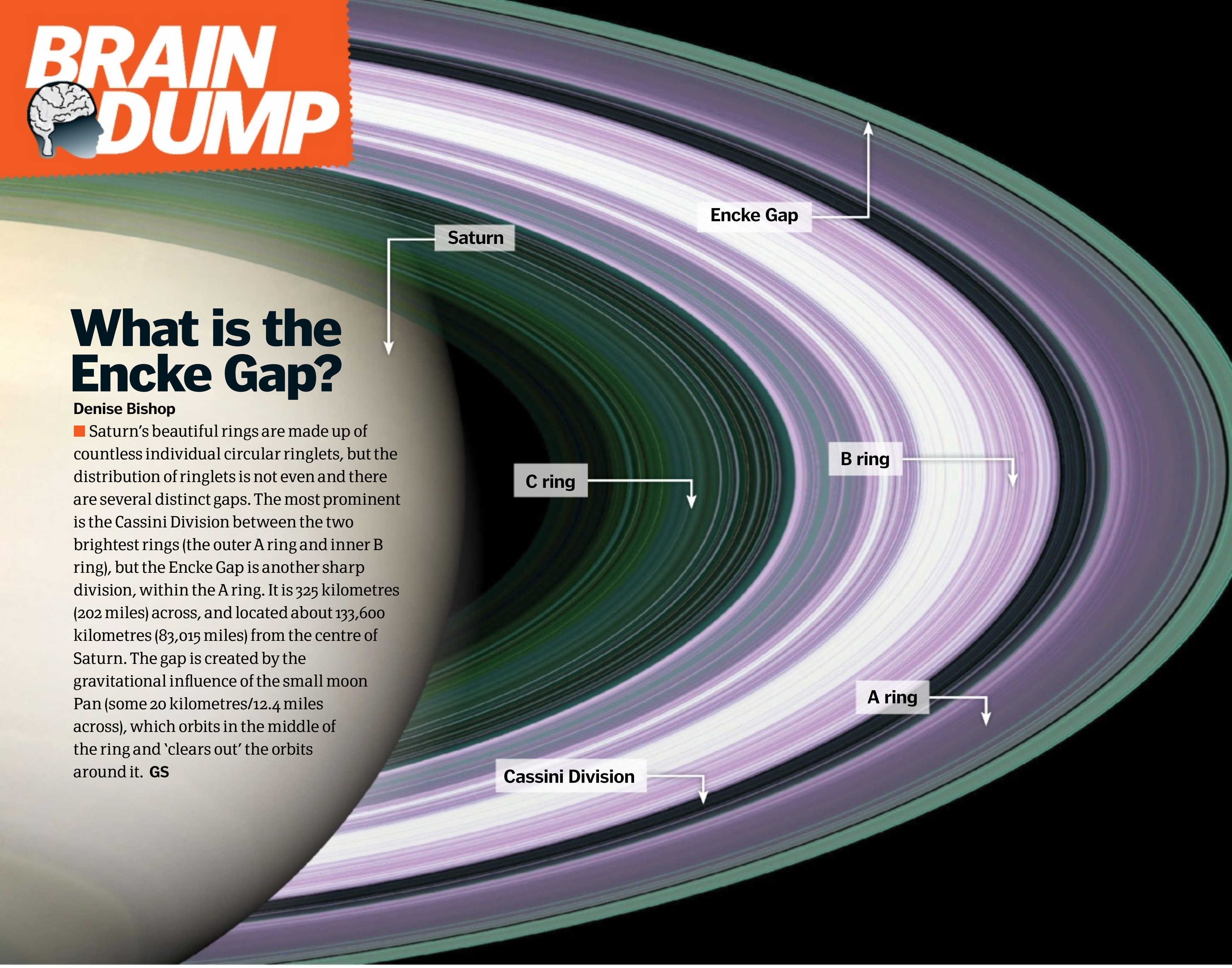
Olivia Ford

Your ears often 'pop' because the tunnel changes the air pressure around the train. Air is always pressing in on your eardrums, but it's usually balanced against the pressure of air inside the ear. Going through a tunnel, air is forced past the train at higher speeds than outside: faster-flowing air exerts lower pressure, so the air inside your ear pushes the eardrum outward. Swallowing or yawning evens out the pressure inside your ear and your eardrum returns to its normal position with a pop. Coming out of the tunnel, your ears may have to pop again to get back to normal. **GS**



How young can astronauts be? Find out on page 84

BRAIN DUMP



What is the Encke Gap?

Denise Bishop

■ Saturn's beautiful rings are made up of countless individual circular ringlets, but the distribution of ringlets is not even and there are several distinct gaps. The most prominent is the Cassini Division between the two brightest rings (the outer A ring and inner B ring), but the Encke Gap is another sharp division, within the A ring. It is 325 kilometres (202 miles) across, and located about 133,600 kilometres (83,015 miles) from the centre of Saturn. The gap is created by the gravitational influence of the small moon Pan (some 20 kilometres/12.4 miles across), which orbits in the middle of the ring and 'clears out' the orbits around it. **GS**

COOL FACTS

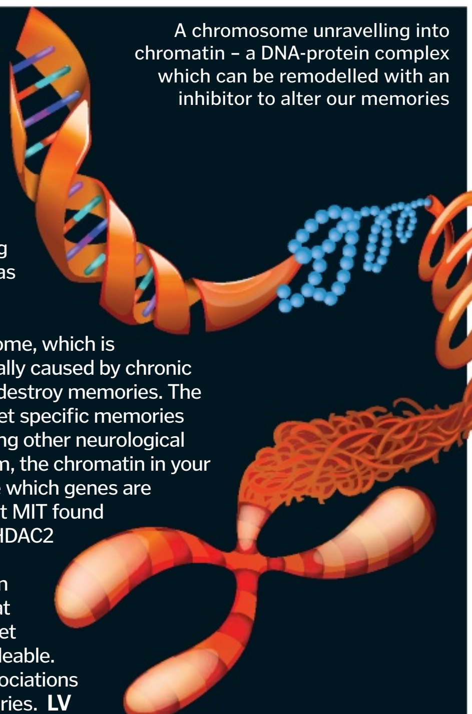
There are no age restrictions to be an astronaut

NASA sets no age restriction on its astronauts, but you need extensive qualifications and experience to be considered, so the youngest person selected so far has been 26 years old. Similarly, the European Space Agency has a preferred age range for applicants of between 27 and 37.

Is it possible to erase memories?

Ken Flett

■ Absolutely. Brain injuries from blunt impacts can cause retrograde amnesia (forgetting previously stored memories), as well as anterograde amnesia (losing the ability to form new memories). Korsakoff's syndrome, which is a vitamin B1 deficiency, generally caused by chronic alcoholism, is another way to destroy memories. The challenge is being able to target specific memories and erase them without causing other neurological damage. When memories form, the chromatin in your brain cells is altered to change which genes are switched on or off. Research at MIT found that a type of drug, called an HDAC2 inhibitor, could affect this chromatin restructuring. When tested on mice, they found that fearful memories could be reset by making the brain more malleable. This allowed new, positive associations to overwrite the fearful memories. **LV**



A chromosome unravelling into chromatin – a DNA-protein complex which can be remodelled with an inhibitor to alter our memories

Why have some birds lost the ability to fly?

Mary W

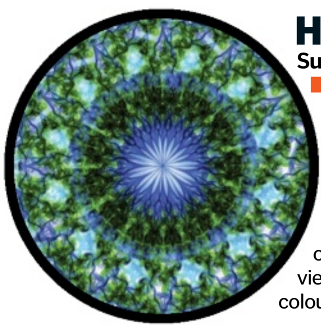
■ Flight is an expensive strategy. Flight muscles make up about 20 per cent of the total weight of a flying bird and reducing this muscle mass allows birds to survive on a lower-energy diet. Flying lets birds escape from predators but remote islands often don't have land predators anyway. For ostriches and emus, evolving a large body was a better defence against predators than flying. Water-loving penguins, meanwhile, probably evolved from diving birds whose bodies were specialised for swimming at the expense of flying. **LV**

Does the colour red really make bulls angry?

Gareth Menzies

■ Humans and some primates can see three primary colours (red, green and blue) but most other mammals, including cattle, see two: blue and yellow. Bulls can see green, because this lies between blue and yellow, but red just looks the same as yellow to a bull. The reality is that it's not colour that makes a bull angry. In the bullring, it's the flag movement and the constant taunting from the matador. In a field, it is the perceived challenge to the bull's social dominance. A threatened bull will attack you regardless of your colour scheme.

Today the sport is steeped in great controversy, with people in Spain divided between those who see it as part of their country's heritage and those who see it as a barbaric way to treat animals. **LV**



How do kaleidoscopes work?

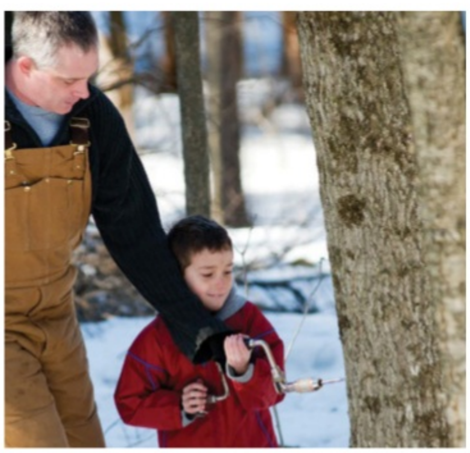
Sue Ling

■ Kaleidoscopes consist of two main parts – mirrors and coloured objects such as beads. The mirrors are placed at angles to each other (commonly 60 degrees) and form a tunnel through which you can look. Light comes in from the opposite end of the tube to the viewing lens and interacts with the coloured beads. The mirrors make multiple reflections of the same image, generating intricate symmetrical patterns. The coloured objects are usually free to move around and so even slight movements can create a completely new pattern. Some kaleidoscopes use oil-filled compartments instead of objects, generating floating images that keep moving after you turn the chamber. **RS**

How do you tap maple syrup?

Gene Rushbrooke

■ The first thing you need is a maple tree. The roots of the tree store starch, which gets converted into sugars to feed the tree, allowing new buds to grow. Sap moves up from the roots of the tree, so finding a nice thick root is best. With a hand drill pointing slightly upward, drill about the same length as your little finger into the tree until sap starts to drip out. Hammer a spout into the hole until it sits snugly, preferably one with a hook so you can hang a bucket to collect the sap. Cover the bucket. Take it home. Boil it. Make pancakes. **RS**



Which is the most dangerous sport?

Moritz Ingle

■ Defining the world's most dangerous sport is not straightforward, largely due to a lack of statistics and reluctance among sport governing bodies to publicise injuries and deaths. However, there are some contenders that come immediately to mind when comparing the number of fatalities versus number of participants in certain sports. The International Isle of Man TT Race is a motorcycle-racing event that is statistically the most dangerous race in the world, with 240 deaths between 1907 and 2009. Cycling has the largest number of total injuries and fatalities, but this doesn't paint a clear picture, since the number of cyclists far exceeds the number of participants in most other sports. Studies have shown that horse riding is statistically the most dangerous, with jockeys expected to have a serious injury for every 350 hours of riding, making jockey insurance premiums among the highest of all professional sports. **RS**

What is vertigo?

Connie Topp

■ Vertigo is a specific type of dizziness which is brought on by disturbances to either the inner ear or to parts of the brain associated with vision and balance. The term is often incorrectly used to describe dizziness at a great height, while the correct term for this is acrophobia. While these two conditions can interact, as feelings of vertigo can induce a fear of heights, they are not the same. Symptoms of vertigo include a sensation that your environment is moving, spinning or tilted in some way. Fluid in the inner ear is crucial for our sense of balance and a common cause of vertigo can arise from excessive fluid buildup or inner ear infections. **RS**

21st-century encyclopaedia

■ Find out whether it really is possible to resurrect dinosaurs in the latest edition of **Brain Dump – How It Works**' digital sister magazine. In issue 12 you'll not only discover if *Jurassic Park* is possible, but you'll also find out how to grow a bonsai tree, how toothpaste is made, the origins of the ninja throwing star and many more trivia snippets. **Brain Dump** is a mini encyclopaedia, packed with incredible facts and jaw-dropping photos. You can get each new issue on the first day of every month from iTunes or Google Play. If you have a burning question, you can ask us on Twitter @BrainDumpMag or **www.facebook.com/ BraindumpMag**.

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Checklist
- ✔ Roomba vacuum
- ✔ Floor mopper
- ✔ Gutter clearer
- ✔ Flymo mower
- ✔ Navibot vacuum
- ✔ Smart thermostat
- ✔ Automower
- ✔ Aquarium cleaner

Domestic robots

Put your feet up and let these bots do the chores…

Time is precious these days. What with all those series to watch on Netflix, who has time to do housework? Luckily, that's all taken care of with these program-and-go robots. So whether it's vacuuming, mopping, mowing or even intelligent home heating you need, let these machines take care of the chores while you sit back and relax…

Even if you forget to set the Robosnail to go, after 24 hours it will automatically start cleaning away.

This mower is fitted with a sensor that immediately stops the blade when it is lifted up to prevent accidents.

Nest's Auto Away function can tell if anyone is in the house and adjusts the temperature accordingly. It can even tell the difference between humans and pets.

The On-Board Scheduling System can learn seven set times when it can clean without getting in your way.

A camera is the Navibot's secret to navigating your house; it can shoot at 30 frames per second.

The Braava uses the NorthStar Navigation System as internal GPS so it can return to where it left off.

1 Tank cleaner

Robosnail
£249.99
fishkeeper.co.uk
This little machine takes all the effort out of cleaning your fish tank. It works by having one half inside the tank, held in place by the other half, which clamps both to the glass with magnets – up to ten millimetres (0.4 inches) apart. This lets you clean the viewing panel without having to empty out any water. It can also work autonomously; just tell it when to clean and it will polish up the glass a treat.
Verdict:

2 Mow no more

Flymo 1200R
£1,299/$1,559.99
flymo.co.uk / best-mower.com
This mower doesn't do quite as much as the Automower but it's still a remarkable machine. Set up a boundary with cables, program how long you want it to mow for and away it goes. It will do up to 400 m^2 (4,300ft^2), but that will take about 13 hours. However, its innovative random movements do leave you with a perfect lawn and it does take all the physical work out of mowing.
Verdict:

3 Smart heater

NEST Thermostat
£249 / $249
nest.co.uk / nest.com
Sleek and beautiful are not often used to describe a thermostat, but the Nest is both. The iPod-style wheel is very intuitive and you can change the temperature, program times and see your energy savings with ease. With the app you can alter settings remotely – great for pre-warming your home. The Nest is easy to use and saves you money – so really, it's a no-brainer.
Verdict:

4 Auto vacuum

iRobot Roomba 660
£419.99 / $TBC
www.irobot.com
The Roomba is the best-known robotic vacuum cleaner on the market. Compact and lightweight, it needed only an hour of charging before being put to work. Tests involved crumbs and torn paper and it identified the messiest areas with its acoustic Dirt Detect tech and spent longer cleaning them, before returning to its recharging station. Virtual Walls also enable you to set up no-clean zones.
Verdict:

5 Mop-a-lot

iRobot Braava 380
£259.99 / $299.99
www.irobot.com
Those of you who have wooden floors know the frustrations of mopping. Water gets everywhere, the floor takes ages to dry and you'll inevitably walk over an area you've just cleaned. The Braava changes all that. Sleek and light, this machine has a host of features. It can dry-clean 92m^2 (990ft^2) and wet-clean 32m^2 (344ft^2), which should be more than enough to get your kitchen and bathroom sparkling.
Verdict:

6 Pet hair buster

Samsung Navibot CornerClean
£495 / $N/A
www.amazon.co.uk
The Navibot is another vacuum cleaner that charges itself on a docking station and can be set free to hoover away. It can get into the most difficult of spaces and return to where it left off if interrupted. Its selling point is its ability to pick up pet hair and prevent it from getting stuck in the brushes. Capable of holding 0.6l (21oz) of dust, once it's programmed you can leave it to get the job done.
Verdict:

7 Constant gardener

Husqvarna Automower 330X
£2,500 / $TBA
www.husqvarna.com
The Automower trims your lawn daily to keep it neat year round. You can set it to mow when you want and, after mapping out your garden, you can leave it to cut away. One of its best features is that it works equally well in the rain and the design means it shouldn't miss any flat grass. The frequent mowing means grass gains nourishment from the clippings.
Verdict:

8 In the gutter

iRobot Looj 330
£249.99 / $299.99
www.irobot.com
The Looj aims to banish all those frustrating weekends clearing leaves and debris from gutters. The caterpillar-style tyres push the 5cm (2in)-high machine along, while the four-stage auger lifts leaf matter up and out of the gutter in a sweeping motion. It's capable of clearing a 10m (30ft) stretch of guttering in five minutes, which is a whole lot faster – and safer – than doing it yourself.
Verdict:

EXTRAS

Since you've no housework to do, why not check these out?

BOOK

Speculative Everything: Design, Fiction, And Social Dreaming

Price: £19.95/$29.95
Get it from: mitpress.mit.edu
Take a spin into the future of product design and innovation. Find out how the solar kitchen restaurant, cloud-seeding truck and flypaper robotic clock could be helping us live in years to come.

APP

Nest Mobile

Price: Free
Get it from: itunes.com & play.google.com
The partner app to the Nest thermostat, if you're out and about and the weather changes you can ensure your house will be nice and toasty when you return. You can also change settings from your sofa if you're too comfy to move.

WEBSITE

androidworld.com

If you want to keep up with what's happening on the robot scene, Android World is great for the latest news in domestic robots, the future of robotics and plenty of other interesting bot-based trivia.

The Automower adjusts to the season, increasing or decreasing the amount it cuts depending on the weather and how much the grass has grown.

The lithium-ion battery provides the Looj with enough juice to clean about 61m (200ft) of guttering per charge.

GROUP TEST
Putting products through their paces

eReaders
Meet the gadgets that will slim down your holiday reading…

The built-in audio player lets you listen to downloaded audio books too.

The X-Ray function lets you find places in the book where certain characters and places are mentioned.

1 Prestigio MultiReader 5664

£109.99/$N/A/€142
www.maplin.co.uk / www.prestigioplaza.com
The MultiReader Supreme 5664 looks great as you open the box and see the black leather carrying pouch, but unfortunately looks can be deceptive. The large edges around the 15.2cm (6in) screen make it look too bulky and the overly smooth finish makes it difficult to grip with just one hand. While the text is clear and it's straightforward enough to adjust the size, the screen is quite reflective so direct sunlight or artificial light make it very difficult to read. The touchscreen is slow to respond and the load times are frustratingly long. One of the upsides is that there are over 250 pre-installed books, although only ten of them are in English. However, the Prestigio website does have thousands of free and paid-for books so if you are able to put up with the delayed reactions, the MultiReader Supreme 5664 does offer a healthy choice of freebies. As a basic eReader, this model does the job, but at virtually the same price point as the others in this test, we'd like it to be slimmer and the load times to be quicker.
Verdict:

2 Kindle Paperwhite

£109/$119
www.amazon.com
The Kindle Paperwhite is Amazon's latest offering on the eReader market. Being Amazon's eReader, there is a near-endless supply of books for you to work through and the display is very easy on the eyes even over long periods. The functionality couldn't be more straightforward; one simple two-fingered swipe allows you to increase the text size, another sweep lets you skip through the novel's pages, and a final swipe will bring up all the menu options.

The lack of any buttons – other than for power – is a tad disconcerting at first, but makes for a sleek design. The new Kindle turns pages 25 per cent faster than its previous incarnation and the touchscreen is superbly responsive. Only the far left-hand side of the screen takes you back a page, meaning that whichever hand you're holding it in, you can flick to the next page effortlessly.

Being able to adjust the backlight depending on ambient light conditions is a fantastic feature, while the ability to re-order your reading collection is useful if you have a lot of books to juggle. The Kindle has always been the trailblazer in the world of eReaders and the Paperwhite shows it remains at the head of the queue in terms of eBook availability, readability, functionality and style.
Verdict:

Just a three-minute charge will provide enough reading time to get through an entire novel. Fully charged, the battery will last up to two months.

3 Sony PRS-T3

£115/$N/A

www.sony.co.uk

Sony's latest eReader is very easy to use, with a host of handy functions to enhance the reading experience. The time from turning the machine on to settling into a book is under a minute and, if you've only put it to sleep, you can be reading in seconds. It's much lighter than your average novel and the paper-like display means that you don't feel like you've been looking at a screen for ages. It allows you to highlight a word and have the definition pop up instantly if you're reading something tricky and you're also able to make notes on the page and record them – ideal if doing a book report.

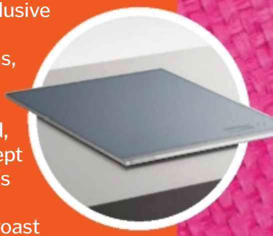
Switching the font size and style is effortless, making it ideal for book lovers who find it difficult to decipher small text. It will hold around 1,200 eBooks, but does have a very useful microSD card slot, enabling thousands more books to be stored. The Sony PRS-T3 is lightweight, stylishly designed and its range of functions – thankfully without a ton of unnecessary gimmicks – makes it one of the best eReaders currently on the market.

Verdict:

ON THE HORIZON

Some more home tech we'd love to get our hands on…

Electrolux Grand Cuisine Vacuum Sealer



Previously the exclusive domain of fancy restaurant kitchens, this handy sealer can instantly vacuum-pack food, allowing it to be kept fresh for longer. It's also perfect for ensuring an even roast when slow cooking.

Tech20 TV

By day, a normal, stylish mirror to hang on your wall. By night, a sleek touchscreen TV with Freeview built in. Note: it also works as a mirror at night and a TV during the day.

Toaster-L washing machine

Hongmin Jin has designed a clever solution for small-load washes. This small toaster-like machine releases detergent into the barrel and is perfect if you only have one or two items to clean.

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Build a treehouse

As summer approaches, here's how to create the ultimate treetop hideaway

1 Pick the tree

First and foremost, the right tree is crucial to any successful treehouse project. Obviously, the sturdier the better. Your aim will be to create a solid structure that won't be affected by the elements, so your tree of choice will need to have a thick and healthy trunk which can also bear plenty of weight. Select a tree where the branches are going to work with you rather than against you to support the treehouse.

2 Make a base

Build the base of the treehouse above two metres (6.6 feet) , so you aren't at risk of a bashed head! Nail four pieces of strong, durable, waterproof timber at a 45-degree angle to the trunk, one on each side. Secure it in place with a few more nails. Now, construct a square base made of four even-sized planks of wood, with a horizontal beam nailed to either side of the trunk to provide further support.

3 Floor it

Lay planks along the width of the base, nailing them on the frame and the base supports. Leave a one-metre (3.3-foot) gap on one side of the trunk to allow room to enter the treehouse. Plug the gap around the trunk with rubber to prevent the boards from shaking too much. If you feel there isn't enough support between the middle and outside of the treehouse, nail another plank onto the frame, halfway between the trunk and the outer edge.

4 Add the walls

The best way to create a solid, sturdy structure would be to secure an upright plank on each corner and layer horizontal beams on top of one another along each side. You could either stack them directly on top of each other or slightly overlap them, like a fence, to help stop rain getting in. Again, remember to leave a space for any windows. When the walls are tall enough, lay planks on top for a roof and nail them down.

5 Finishing touches

Now is the time to make things safe and waterproof. Consider using a piece of tarpaulin or roofing felt on top of the treehouse to prevent any water getting in. Diagonal beams on top of the roof also help to keep rain at bay. If they are not already treated, apply a layer of sealant to the entire structure, which you can either spray or paint on.

In summary...

As long as you have a solid base and support network, putting up a treehouse shouldn't be too difficult. Make sure that before you begin, you have written out a plan with all the dimensions as well as a list of what tools and materials you'll need. Making a mini model can also be a good idea as it often flags up any potential problems.

NEXT ISSUE
- Shoot photos underwater
- Cook a perfect BBQ

Exercise in the office

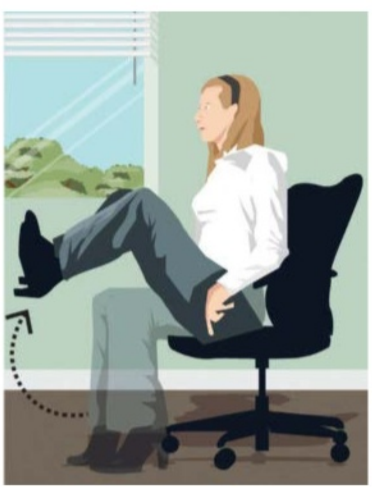
When time for the gym is short, here are some keep-fit tips for working hours

1 Work your arms

First of all we'll start with some exercises for your arms. If you don't need to be typing, squeezing a hand grip as many times as you can will increase the strength of your fingers and forearms. Alternatively, hold a light weight such as a small dumbbell or water bottle above your head. Bend at the elbow until your arm is at right angles, with your hand behind your head. Extend your arm to the starting position and repeat to help combat bingo wings.

2 Stretch your legs

These exercises are more subtle to perform at your desk. Start with your upper leg horizontal and your lower leg at right angles, with the foot flat on the floor. Raise your leg until it is straight, then lower it slowly. Swap legs and repeat, then lift both at once. As your legs gradually get stronger, try holding them aloft for a few seconds before lowering them. You can even continue typing while exercising your legs so work isn't disrupted.



3 Exercise your abs

Abdominal exercises are all about working your core to gain all-round strength, so we're back to the leg lifts again. Carefully sit on the edge of your chair and anchor yourself in by firmly grasping the handles. Make sure the chair can't slide backward. Sit with your upper legs horizontal and your lower legs at right angles. Raise your upper legs as far as they will go, maintaining that 90-degree angle throughout. Lower the legs and repeat.

In summary...

The idea behind office workouts is to be able to tone and strengthen while at your desk. We also recommend getting up and speaking to people rather than emailing and taking the stairs rather than the lift, but if you don't mind a few confused glances, these exercises will keep you trim.

QUICK QUIZ

Test your well-fed mind with ten questions based on this month's content and win an Airfix model of a Boeing 727 airliner!

Answer the questions below and then enter online at **www.howitworksdaily.com**

1. What are the fruiting bodies of inedible fungi called?
2. Where was Theodore von Kármán – of Von Kármán vortices fame – born?
3. In what year did Nikolaus Otto build the first four-stroke engine?
4. Which element is most often used for propulsion in ion thrusters?
5. How much of Earth's land surface does boreal forest cover (in per cent)?
6. In which country is the largest asteroid crater?
7. Which civilisation ruled Jerusalem at the time of the siege in 70 CE?
8. What is the name of the tube used in airspeed indicators?
9. CubeSats are taken into orbit by P-PODs – what does this stand for?
10. How much does each camera capsule endoscopy cost?

ISSUE 59 ANSWERS

1. 450mn **2.** 13.4km^2 **3.** Saturn V **4.** Varicella zoster **5.** 1912 **6.** 4.6m **7.** Solent **8.** Haber-Bosch **9.** Polish **10.** Alec Jeffreys

INBOX
Speak your mind...

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AMAZING PRIZE FOR NEXT ISSUE'S LETTER OF THE MONTH!

DEEP SPACE IN YOUR HOME!

Next issue's Letter of the Month will win a Deep Space Home Planetarium & Projector. Explore the universe from the comfort of your living room with stunning photos taken by NASA of constellations, spacecraft and planets projected onto your wall or ceiling.

Letter of the Month

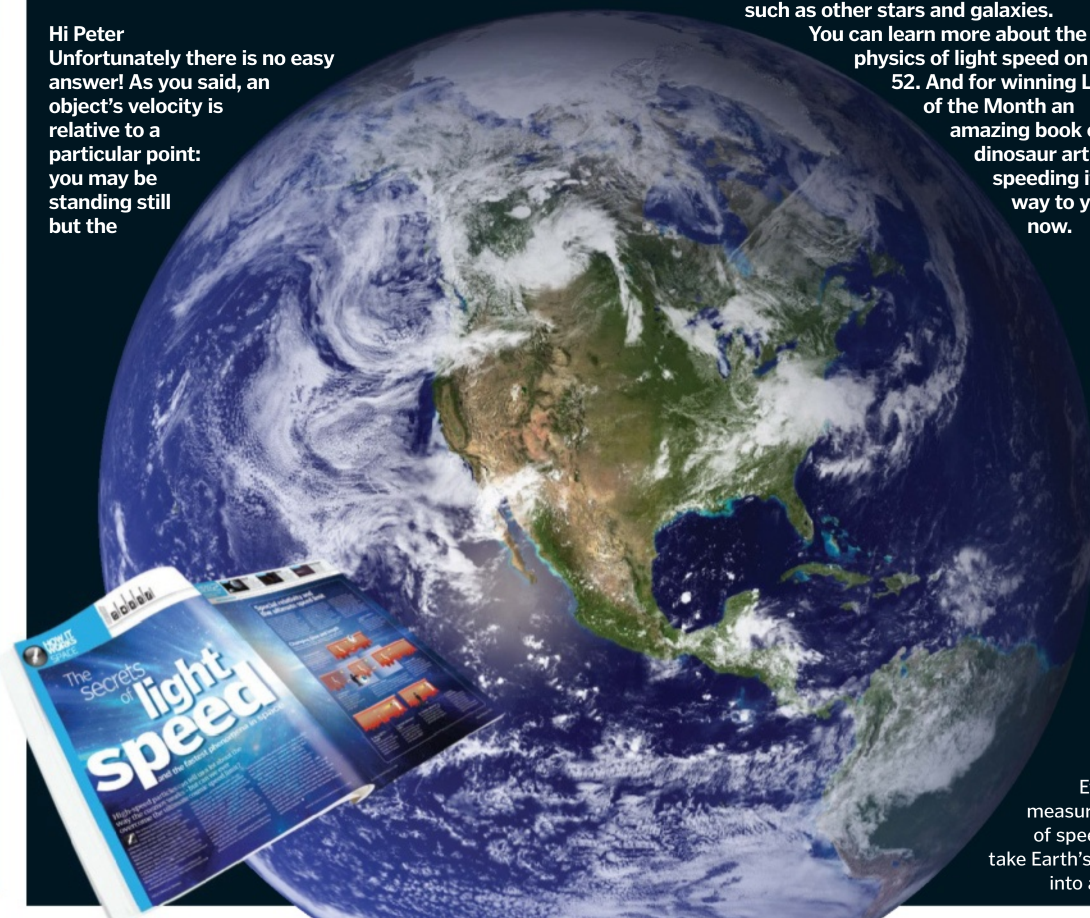
Need for (light) speed

Dear **HIW**,
I keep reading that as we travel closer to the speed of light, time slows down (eg Brain Dump issue 58: 'Do we age differently in space?'). I've wondered where we take the measurement of speed from as it's only relative to a certain point. An observer on Earth is also moving around the planet, the planet is moving around the Sun, the Sun is moving around the Milky Way, etc.

Thanks in advance as this has puzzled me for some time.
Peter Laidler

Hi Peter
Unfortunately there is no easy answer! As you said, an object's velocity is relative to a particular point: you may be standing still but the Earth is moving around the Sun at around 30 kilometres (19 miles) per second, and therefore so are you. Scientists use what are known as reference frames to describe motion, and these can vary depending on what needs to be measured. In most cases, such as determining the speed of a car, we assume that Earth is stationary. For astronomical objects the 'local standard of rest' (the average motion of our star and the surrounding material in its neighbourhood of the Milky Way) is used to judge the velocities of distant objects such as other stars and galaxies.

You can learn more about the physics of light speed on page 52. And for winning Letter of the Month an amazing book of dinosaur art is speeding its way to you now.



Everyday measurements of speed don't take Earth's motion into account

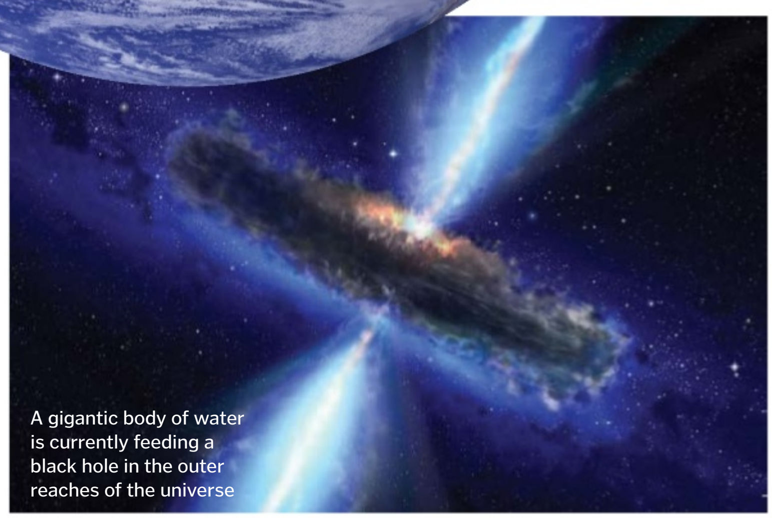
A burning issue

Hi How It Works!
Your magazine is amazing!
When I came back from holiday I found a burn on the PVC rim of the top bathroom window. It was completely charred all the way through. The only reason we could think of was if the shaving mirror had somehow magnified the light from the window and onto the PVC enough for it to burn, but is this possible?
Theo Rangarajan (12)

The shaving mirror does seem the most likely culprit, especially if it has a magnified side. Our guess is that the mirror had the same effect as a magnifying glass does when struck by the Sun's rays. Glass in mirrors and magnifying glasses can concentrate solar energy on a particular point resulting in a high focus of heat. This principle is used by solar power plants such as the PS10 plant in Spain to harness the Sun's energy. With smaller domestic mirrors, this is usually too weak to have any great effect – especially on fire-resistant PVC – but there was clearly enough time (and sunny weather) while you were on holiday for the frame to get charred! A safety lesson for us all.

Water, water everywhere

Hi HIW,
Is it true that there's a giant reservoir of water in space?
Joe Bulger



A gigantic body of water is currently feeding a black hole in the outer reaches of the universe

“The huge mass was equivalent to 140 trillion times the amount of water found in Earth’s oceans”

As crazy as this may sound, Joe, there is! Three years ago NASA claimed to have found a reservoir of H_2O some 12 billion light years away from our home planet. The huge mass was equivalent to 140 trillion times the amount of water found in Earth’s oceans. It is the largest and farthest known source of water in the universe and surrounds and feeds a special type of black hole commonly known as a quasar. In the form of water vapour, it is an important trace gas that gives a fascinating insight into the earlier stages of the universe.

The sky is… green?

Dear **HIW**,
My son has a subscription to your magazine but I often dip into it too… You are never too old to learn something new! I read in issue 59 an explanation for the colour of the sky and realised I'd never read the answer before, including the theory regarding the colours in a sunset/sunrise. However, this has only caused me more confusion now. Shades of blue (blue and indigo) have the shortest wavelength (Sun high in the sky) and the sunsets contain yellows, oranges and reds when the Sun is low in the sky. Why doesn't the sky look green (green is between blue and yellow/orange/red in a rainbow) somewhere between Sun high and Sun low in the sky? Sorry if it's a stupid question – you can't choose your readers! Thanks in advance for an answer.
Kind regards,
Ruth

It's not a stupid question at all, Ruth! You're right, of course, that green is in between blue and red in the visible wavelength spectrum of light. However, green is a colour not highly emitted by the Sun so blue and red constantly overlay it. In between the change-over from blue to red colour skies, the colour of green is shrouded and not seen. When green light arrives in our line of sight together with either red or blue light, our eyes perceive it as yellow or cyan/turquoise, respectively. Moreover, sunlight reflection by molecules in the atmosphere is known as Rayleigh scattering. Our atmosphere only allows certain types of colour wavelength to be seen by our eyes, and green is not one of them. For example, the Sun is actually white rather than the yellow/orange/red we perceive it as. The white light photons are scattered by our atmosphere and the other more prominent colours are what we see.


Differing wavelengths mean the sky can appear both blue and red but not green

What's happening on… Twitter?

We love to hear from **How It Works**' dedicated followers. Here we pick a few tweets that caught our eye this month…

Chris @KRS_OVO
Best magazine ever! My subscription from #Europe finally started :-) #BrainFood

Ollie Iron @Ollie_Iron
Subscription issue arrived of **@HowItWorksmag** today… Have you guys done a 'science behind cyberpunk' article yet?

Desiree Stephens @idesiree1
You'll never guess which one was caffeine. **www.howitworksdaily.com/environment/how-do-drugs-affect-spider-webs/** … via **@HowItWorksmag**

Ollie Iron @Ollie_Iron
@HowItWorksmag Just want to tell you guys you've got a great magazine on your hands. I look forward every month to finding **HIW** on my doormat

dan calvert @danielcalvert3
@HowItWorksmag
just read the article on jet packs. Very detailed keep up the good work.

Jessica DoldingSmith@DoldingSmith
Woop woop, I won letter of the month **@HowItWorksmag**

Hertschick@Hertschick
thank you **@HowItWorksmag** Hexbug spider all received and we love it! have a great day :)

Lolly Skosana @Lolly_Lia
I have a feeling they can RT **@HowItWorksmag**: Can cockroaches survive a nuclear bomb??? **http://bit.ly/1u37lOe**

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SURVIVING PLANET EARTH

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Why are exosuits making us stronger, faster, better?

How are high-altitude balloons changing science and tourism?

How are vehicles made safer through crash testing?

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